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**ASSESSMENT METHODS OF CIRCULARITY  
IN THE BUILT ENVIRONMENT  
– A SCOPING REVIEW**

Master's Thesis in Architecture  
Faculty of Built Environment  
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# ABSTRACT

Ida Salama: Assessment Methods of Circularity in the Built Environment – A Scoping Review  
Master's Thesis  
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The motivation behind this research is the immense use of energy and virgin materials in the construction industry on a global scale. The circular economy can be seen as one solution to both issues. Moving towards a circular economy is a significant paradigm shift that requires change in systems, practices, and attitudes. The change itself, especially when this vast and significant, needs a scientifically proven basis and transparency.

The topic of this thesis is the assessment of circularity in the built environment. This work examines what assessment methods for circularity are 'out there' and on which levels they are studied, and applied to subjects, how they are studied and who studies them. The chosen research method for the thesis is a scoping review, and the research material for the work was collected from the Scopus database. The PRISMA screening review guidelines were used to ensure reproducibility and transparency.

Circularity in the built environment is studied on four levels: systemic (policies and regulations), macro (city and regional level), meso (buildings), and micro (building parts, components, and materials). The results present how the levels interconnect, but according to the results when operating only on one level the micro level works best on its own. This work demonstrates that circular solutions are assessed with methods and methodologies that are invented for assessing sustainability or measured with indicators that are created for sustainability impact assessment. If only one indicator is used in assessing, e.g., environmental impact, it can be questioned whether it evaluates the circularity of the chosen scope well enough. Life cycle assessment was the most used method or methodology in this review, and only a few completely novel methods or methodologies were found in this work.

A lack of unity in the circular economy description and indicators can be seen in the results of this review and in discourse related to it, and can create confusion with method selection and usage. To support the transition from a linear to a circular economy, the field would benefit from more uniform definitions and standardization. Method development can continue separately on different levels, but attention should be drawn especially to the context in which methods are being used in and transparently disclose this. Further research should focus on more comprehensive assessment of circularity and include qualitative measures, including social-related aspects.

Key words: Circular economy, Built environment, Assessment method, Circularity, Sustainability, Circular construction, Life cycle, Planetary boundaries

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# TIIVISTELMÄ

Ida Salama: Kiertotalouden arviointimenetelmät rakennetussa ympäristössä  
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Arkkitehdin tutkinto-ohjelma  
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Työn taustalla ja motiivina on rakennusteollisuuden valtava energian ja neitseellisten materiaalien käyttö globaalilla tasolla. Kiertotalous voidaan nähdä yhtenä ratkaisuna molempiin ongelmiin. Siirtyminen kohti kiertotaloutta on merkittävä paradigman muutos, mikä vaikuttaa järjestelmiin, käytäntöihin ja asenteisiin. Näin laaja ja merkittävä muutos itsessään vaatii tieteellisesti todistettua perustaa ja läpinäkyvyyttä.

Tämän diplomityön aiheena on kiertotaloudellisuuden arviointi rakennetussa ympäristössä. Tässä työssä tutkitaan, mitä kiertotalouden arviointimenetelmiä on olemassa ja millä rakennetun ympäristön tasoilla arviointimenetelmiä tällä hetkellä tutkitaan ja käytetään, miten niitä tutkitaan sekä kuka niitä tutkii. Diplomityön tutkimusmenetelmä on kartoittava (scoping) katsaus ja tutkimusaineisto on kerätty Scopus-tietokannasta. PRISMA-julkilausuman ohjetta käytettiin toistettavuuden ja läpinäkyvyyden varmistamiseksi.

Rakennetun ympäristön kiertotaloudellisuutta tutkitaan työssä neljällä tasolla: systeeminen (menettelytavat ja määräykset), makro (kaupunki- ja aluetaso), meso (rakennukset) ja mikro (rakennusosat, komponentit ja materiaalit). Tulokset osoittavat että, parhaimpiin arviointituloksiin päästään, kun toimitaan kaikilla tasoilla, mutta myös, että yhdellä tasolla toimittaessa mikrotaso toimii parhaiten. Tämä työ osoittaa, että kiertotalousratkaisuja arvioidaan menetelmillä, jotka on kehitetty tai luotu kestävän kehityksen arviointiin tai joilla mitataan indikaattoreita, jotka on luotu kestävän kehityksen vaikutusten arviointiin. Jos arvioinnissa käytetään vain yhtä indikaattoria, esimerkiksi ympäristövaikutuksia, voidaan kyseenalaistaa, arvioiko se kiertotaloudellisuutta riittävän hyvin valitussa kontekstissa. Tässä työssä elinkaariarviointi oli eniten käytetty arviointimenetelmä, ja täysin uusia arviointimenetelmiä tuli ilmi vain vähän.

Tässä työssä ja siihen liittyvässä laajemmassa keskustelussa huomataan, että kiertotalouden ja sitä mittaavien indikaattorien määrittelyiden yhtenäisyydessä on puutteita, mikä voi aiheuttaa sekaannusta menetelmien valinnassa ja käytössä. Ala hyötyisi yhtenäisemmistä määritelmistä ja standardoinnista lineaarisesta taloudesta kiertotalouteen siirryttäessä. Arviointimenetelmien kehitystä voidaan jatkaa erikseen rakennetun ympäristön eri tasoilla, mutta tällöin huomiota tulisi kiinnittää erityisesti kontekstiin, jossa niitä käytetään, sekä tuoda se avoimesti esiin. Jatkotutkimuksessa olisi keskityttävä kiertotalouden kokonaisvaltaisempaan arviointiin, ja huomioida arvioinnissa kvalitatiivisia mittareita kuten sosiaalisia näkökulmia.

Avainsanat: kiertotalous, rakennettu ympäristö, arviointimenetelmä, kiertotaloudellisuus, kestävyys, kestävä rakentaminen, elinkaari, planetaariset rajat

Tämän julkaisun alkuperäisyys on tarkastettu Turnitin OriginalityCheck –ohjelmalla.

# PREFACE

In secondary school I participated in a competition in which the participants were asked to invent sustainable solutions for households. I remember I returned multiple proposals, unfortunately none of which won the prize. Nevertheless, this experience has remained strong in my memories because it was then that I first became aware of the themes of sustainability in my everyday surroundings. During my studies at the School of Architecture in Tampere in the 2010s, the themes of sustainability have received increasingly and rightly more attention. Climate change and biodiversity loss have already literally changed the environments we live in. This creates anxiety, which can, in my opinion, be healed with action.

While doing my master's studies, I took an interest in studying existing built environments, such as built heritage, conversions of buildings, restoration, and maintenance. These themes have been closest to my heart in my professional career as well, and I have been lucky enough to have been able to work on such projects. Maintaining our built infrastructure, whether old or new, is the best and most sustainable practice. As a part-time teacher at the Faculty of Built Environment, it is wonderful to see how new students want to learn more about sustainable ways of building and how we are increasingly able to include matters of sustainability already in the basic education of architecture.

Personally I had two main goals with my thesis work. First, to expand my knowledge regarding sustainable built environments by learning about circular economy in that context. Second, to learn about academic research and writing. With both goals I, a bit stubbornly, jumped in at the deep end. A lot of learning has happened, and I believe these goals have now been met, although learning will surely continue.

I would like to express my gratitude to my first supervisor, University Instructor Dr Tapio Kaasalainen for the help, kind and professional feedback, and for believing in me to finalize this project. I would also like to thank my second supervisor, Professor Dr Sofie Pelsmakers for guiding my work along the way and Professor Dr Satu Huuhka for helping me find the topic for this work.

Furthermore, I want to thank my family and friends for their endless support and patience along the way, it has been irreplaceable. Essi, you have been my mentor in many ways in my life, and in this process as well, thank you for all the advice. Enrique, thank you for being there during the highs and lows and for believing in me.

In Helsinki, Finland, on 21<sup>st</sup> of August, 2024

Ida Salama

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# LIST OF FIGURES, SYMBOLS AND ABBREVIATIONS

BE	Built environment
C2C	Cradle to cradle
CE	Circular economy
CO <sub>2</sub>	Carbon dioxide
DfD	Design for disassembly
DfS	Design for sustainability
DfX	Design for excellence
GHG	Greenhouse gas
LCA	Life cycle assessment
LCC	Life cycle costing
LCIA	Life cycle impact assessment
PSS	Product-service systems
MFA	Material flow analysis

# 1. INTRODUCTION

## 1.1 Background, aims and context

This thesis studies circularity in the built environment, especially assessment methods in circularity. Circular economy in the built environment can be seen as an ancient method in the history of the built environment, but it has gathered momentum within the past few decades because of the unsustainability of the industry and environmental issues related to it. The material and energy consumption within the construction industry is not on a sustainable basis and cannot last as it is in the future. This is one of the main reasons why this work was done.

This work tries to map what assessment methods for circularity are 'out there' and how assessment methods are currently used, how they are studied, who studies them and on which levels they are studied and applied on subjects.

The topic of this thesis is assessment methods of circularity in the built environment. The studied levels that cover built environment are according to Pomponi & Moncaster (2017) framework and are as follows: systemic (policies and regulations), macro (city and regional level), meso (buildings), and micro (building parts, components, and materials). Civil engineering infrastructure (e.g., bridges) in the built environment has been left out. The main goal of this work was not to determine what circular economy is or what it is in the built environment context. The focus of the work was on the assessment viewpoint.

One of the reasons for this thesis to be done was to broaden the knowledge of the writer on circular and sustainable matters in the built environment and hopefully readers of this work as well. The aim of this work is to better understand circular economy in the built environment and especially through the lens of evaluation methods of circularity, what they measure, how are they used and on which levels in the built environment.

This work also partly became to be because of an EU funded project called CIRCuIT, which had a need for a review of this type and topic. Unfortunately, the cooperation was not able to be taken forward. The literature material, which was delivered from the project and was meant to be the basis for the work, was ultimately not used and material search was done by the writer.

## 1.2 Research problem and research questions

The motivation behind the research is the immense use of energy and virgin materials in construction industry and how to tackle this. Circularity can be seen as one solution to both issues. Moving towards circular economy is a significant paradigm shift that requires change in systems, practices, and attitudes. The change itself needs a scientifically proven basis and transparency.

One occurring problem globally and related to the shift towards a more sustainable or circular future is greenwashing. That means that products or practices can be given false or misleading environmental benefits, and this extends to the construction industry. These issues relate to transparency of practices, measurability, and comparability of options. Raising question is: “How do we understand which option is most suitable for a specific circumstance?” Assessment methods are a vital mean for providing factual data and evidence for transparent decision-making and ultimately to steer the construction industry to a more sustainable direction. The research problem is the knowledge gap in what kind of and how assessment methods of circularity are used in the built environment and construction industry.

A preliminary study was made at the beginning of the process with an aim to verify the presumed starting point that circular assessment methods for built environment exist. This was done by examining whether assessment methods of circularity are researched and/or used in the built environment in general. Another aspect that was examined was whether the methods were purely theoretical or were the studied methods used in a case study. The outcomes of the preliminary study are included and described in the results section.

On basis of the preliminary study, three consecutive questions were set. The main research question is: (1) ‘What kind of methods are used to assess circular economy or circularity in the built environment?’. Within the scope of the question, a look to metrics related to the assessment methods was also done. The first research question led to following questions (2) ‘In which levels the methods are used?’, and (3) ‘Which life cycle stages are considered in circularity assessment?’. Consecutive questions (2) and (3) were formed because there was a need to clarify how the methods were used.

### **1.3 Research method and structure of the work**

The chosen research method for the thesis is a scoping review. The premise was to write a literature review on the topic, firstly a systematic review and later the method was defined to be a scoping review. This was done due to the nature of the formed research questions, which were more about forming a broader view on the topic rather than trying to find a specific answer to a specific question. Scoping reviews have a broader approach compared to systematic reviews and aim to map literature and address a broader research question and therefore a scoping review is often done before systematic literature review (Munn et al., 2018; Peters et al., 2015). PRISMA screening review guideline was used to secure replicability and transparency. It stands for Preferred Reporting Items for Systematic reviews and Meta-Analyses and is a standard format for reporting systematic reviews. The search literature was collected from Scopus database and limited to peer-reviewed publications.

This work is divided into six sections, starting with the introductory section (1), and continuing to the overview of the research context (2). After that methodological background is introduced thoroughly, review questions are refined, and a research framework presented (3). The research process is carefully explained in section (4). In section (5) the results of this review are introduced.

In this section general attributes and descriptive perspective are given and after that, key findings and limitations are presented. In the final section (6) of this thesis conclusions are drawn.

This work is largely based on academic publications and due to the topic and methodology of the thesis. Some professional and organizations' written sources have as well been used as references. The theme of this work is topical and relates to a larger ongoing discourse about sustainable practices in the built environment, and especially discusses what kind of part circular economy has in that context. This work shows how sustainability and circularity overlap, which can be used for the benefit of other than circular or sustainable goals. This work highlights the need for further research within this topic.

## 2. OVERVIEW OF THE RESEARCH CONTEXT

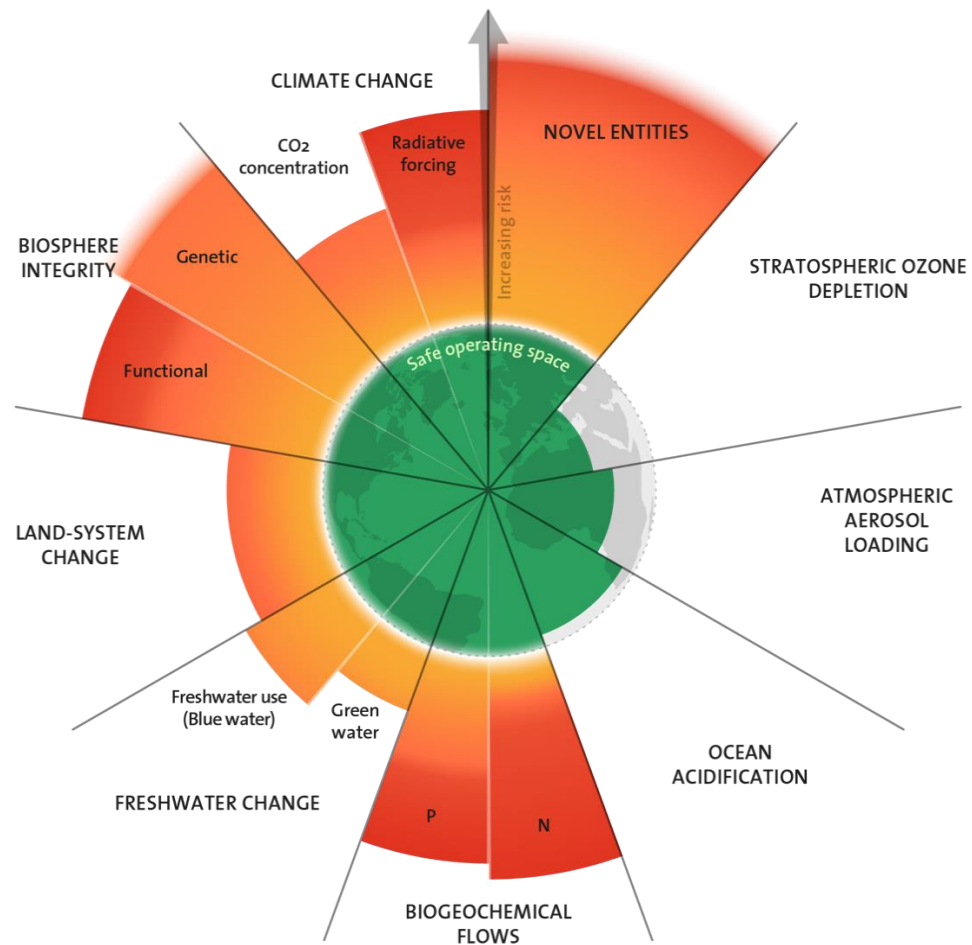
### 2.1 Planetary boundaries and Sustainability approach

According to the Ellen MacArthur foundation, we live in an era where us humans are reaching and exceeding the limits of this planet (Rockström et al., 2009). The technological development and fossil fuel-based energy consumption after the industrial revolution, which started approximately two centuries ago, led to a one-of-a-kind transformation in societies and ecosystems. All this led to an exponential accumulation of carbon from land and ocean carbon reservoirs into the atmosphere. The changes that humankind has made to the carbon and nutrient cycles, Earth's surface, atmosphere and oceans are so profound that it has led to the use of the term Anthropocene. (Raupach & Canadell, 2010) While climate change, driven by atmospheric carbon, is a major issue, it is only one result of exceeding planetary boundaries.

Research by Rockström et al. (2009) defines the biophysical limits of a stable and resilient planet through nine boundaries: (1) Climate change (CO<sub>2</sub> concentration, Radioactive forcing), (2) Novel entities which usually refer to entities created by human activities with unknown effects on the Earth system e.g., plastic, (3) Stratospheric ozone depletion, (4) Atmospheric aerosol loading, (5) Ocean acidification, (6) Biogeochemical flows, (7) Freshwater change (Freshwater use, Green water), (8) Land-system change, and (9) Biosphere integrity (Functional, Genetic). Currently, only three boundaries (Stratospheric ozone depletion, Atmospheric aerosol loading, and Ocean acidification) are within safe operating limits, as shown in Figure 1. Figure 1 presents the state of planetary boundaries in Autumn 2023. The remaining six boundaries are already in the zone of increasing risk. The aspect of planetary boundaries brings attention to humanity's exploitative behaviour. For a sustainable future, we must react to Earth's limits by reducing emissions and the excessive consumption of energy and finite resources.

In this context, sustainability becomes a crucial framework for guiding human activities within these limits. Sustainability is typically defined through the three dimensions of environment, society, and economy (Purvis et al., 2019). The definition, as it usually is today understood, was first brought up in the 1980s in a UN Brundtland Commission report, where they defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Pareja-Eastaway, 2012, p. 502). The UN's 2030 Agenda, created in 2015, addresses sustainability goals with 17 Sustainable Development Goals (SDGs), which aim to end poverty and inequality while promoting prosperity and protecting the planet. Sustainability and sustainable development are closely related terms, and both terms recognize the three-dimension definition (Purvis et al., 2019). Sustainability can be seen as a normative concept, i.e., how things should be or should be done, whereas sustainable development can be seen as a principle that directs or governs action or policies (Harrington, 2016). The importance of sustainability is emphasized because the SDGs are widely recognized and endorsed at both

global and political levels, thereby making them a crucial framework for guiding sustainability efforts.

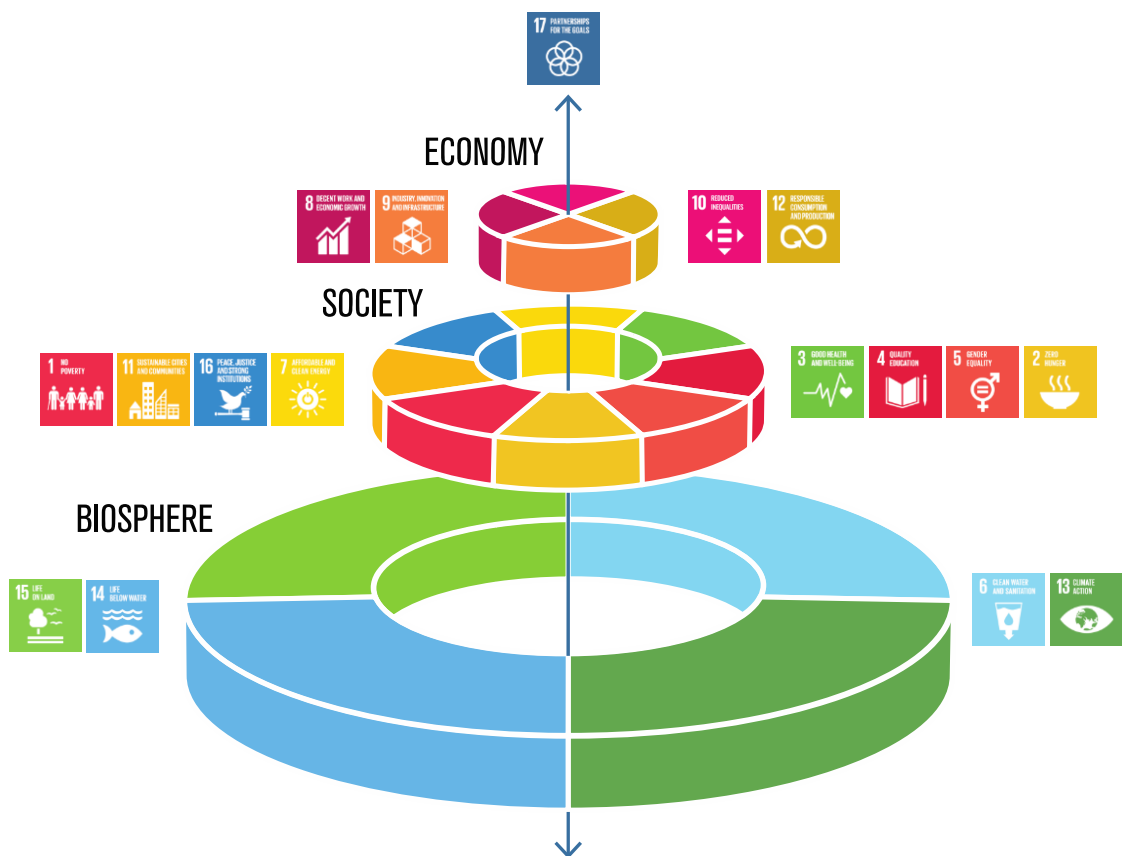


**Figure 1. Nine planetary boundaries by Azote for Stockholm Resilience Centre in Autumn 2023. The sphere of the Globe represents the boarder of the safe operating space. (Planetary Boundaries - Stockholm Resilience Centre, n.d.; Rockström et al., 2009)**

The 2030 Agenda includes goals such as No poverty (SDG 1), Zero hunger (SDG 2), and Climate action (SDG 13). In year 2015, all UN member countries adopted this agenda. Issues that are addressed with goals are energy, climate, oceans and clean water, urbanization, transport, science, and technology. (THE 17 GOALS | Sustainable Development, n.d.) Ultimately, it is a political decision of each UN member country to act on these goals. For instance, Finland's sustainable development efforts are coordinated by the Finnish National Commission on Sustainable Development under the Prime Minister's Office (Mitä on Kestävä Kehitys? - Ympäristöministeriö, n.d.).

The three-level relation between environment, society and economy has often been presented in a way where the aspects are seen as equal and in a visual presentation as intersecting circles, or equal pillars of sustainability. A nested diagram sets a similar division between the aspects. This schematic presentation has been taken further in a wedding cake diagram that has been

created by Azote for the Stockholm Resilience Centre. The illustration considers the UN's sustainable development goals and the hierarchy between the sustainable dimensions (see Figure 2). In the figure, the term environment is replaced with the term biosphere. The figure presents the hierarchy between the three levels of sustainability, where the biosphere or environment can be seen as the foundation for any other layer. Yet there has been criticism over the sustainable development goals because they do not adequately address planetary boundaries (Kotzé et al., 2022). Planetary boundaries view the whole setting from a biosphere or environmental perspective, and the approach does not consider societal or economical viewpoints. Many SDG values and goals are irreplaceable from equity and social welfare perspective, but it could be questioned whether the SDGs create strong enough means to tackle environmental issues from a planetary perspective. Many values and targets the SDGs create are, e.g., present in the ways sustainability is assessed. Therefore, it is vital to understand the foundation of sustainability and how it differs from the planetary boundary approach. Understanding both the planetary boundaries and sustainability frameworks is essential for developing strategies that respect Earth's limits while promoting human well-being and development.



**Figure 2. The UN SDG wedding cake. Azote for Stockholm Resilience Centre, Stockholm University (The SDGs Wedding Cake - Stockholm Resilience Centre, n.d.)**

In a built environment, sustainability addresses the three sustainability pillars: environmental, social, and economic aspects. Impacts related to sustainability, for example, environmental

impact, are used to verify long term changes and they have a reference to which results are compared. Key principles include reducing resource consumption (energy, water and materials), minimizing environmental impacts (pollution, greenhouse gas emissions), and enhancing the health, safety, and well-being of occupants and communities. Buildings, infrastructure, and urban spaces play a crucial role in achieving sustainability goals, as will be demonstrated in section 2.2. Buildings alone contribute significantly to global energy use, resource consumption, and greenhouse gas emissions. To mitigate its environmental impact the construction industry must adopt sustainable practices. This includes using sustainable materials, improving energy efficiency, and integrating renewable energy sources. On top of environmentally sustainable design and construction, the social and economic dimensions of sustainability in the built environment create healthier living spaces, reduce operational costs, and can promote economic development through green jobs (“IPCC 6th Assessment Report - 9. Buildings,” 2023, p. 1080). Therefore, transforming the built environment into a more sustainable system is essential to address the broader challenges of sustainability and ensure the well-being of future generations.

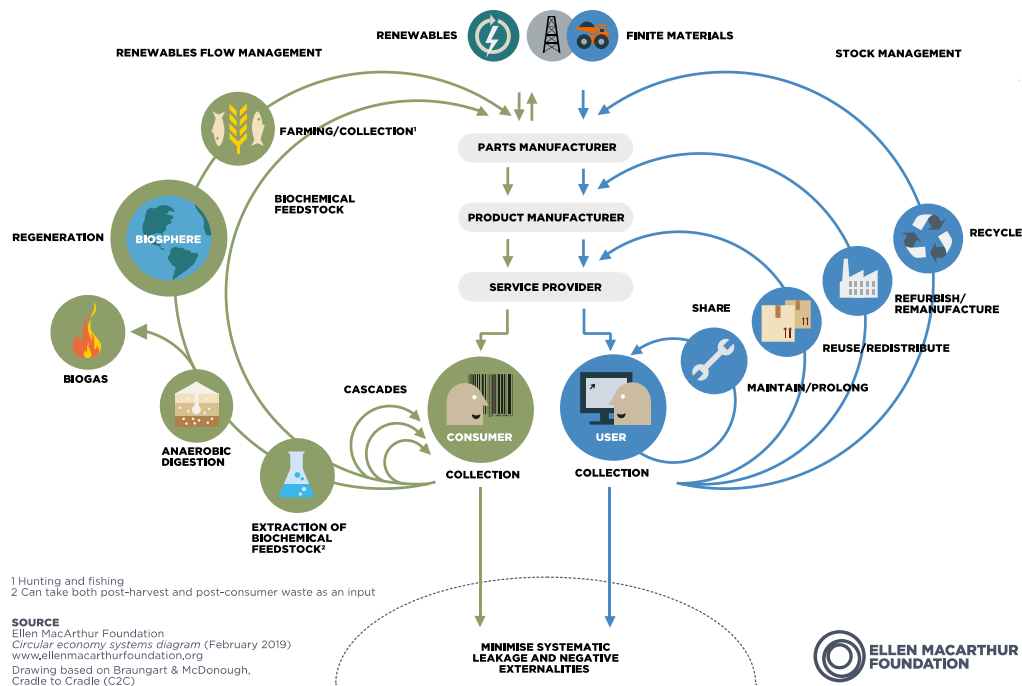
## **2.2 Built environment context**

Many phenomena that are megatrends or otherwise define humankind development in the future are in close relation to built environment sustainability, and planetary integrity, such as population growth, urbanization, and higher living standards. Population growth and the simultaneously happening global migration from rural areas to urban will result in the level of material consumption increasing (Wilmoth et al., 2022). Mining, quarrying, and industrial forestation lead to loss of soil, environmental degradation (pollution), and the depletion of natural resources. Many of the first mentioned are means to collect materials that are used as primary building materials. The construction industry is responsible for almost 50% of worldwide annual resource consumption (OECD, 2019). Global building material consumption tripled between 2000 and 2017 from 6.7 billion tons to 17.5 billion tons and the most used building materials were aggregates, concrete and bricks (Huang et al., 2020). According to Huang et al. (2020) the largest growth in building material use during this period was in China and with rapid urbanization accounting for more than half of the global use of building materials in 2017. Between 2000 and 2017 the use of building materials in Europe and North America stabilized and even declined. (Huang et al., 2020). Construction and demolition waste makes up 30% of total global waste, with an annual average of 35% being disposed of in landfills. (Purchase et al., 2022). IPCC 6<sup>th</sup> Assessment Report discloses: “Total greenhouse gas (GHG) emissions in the building sector reached equivalent 21% of global GHG emissions in 2019, of which 57% were indirect carbon dioxide (CO<sub>2</sub>) emissions from offsite generation of electricity and heat, followed by 24% of direct CO<sub>2</sub> emissions produced on-site and 18% from the production of cement and steel used for construction and/or refurbishment of buildings”. On top of that, the construction industry is responsible for a third of energy use. (“IPCC 6th Assessment Report - 9. Buildings,” 2023, pp. 955, 957)

## 2.3 Circular economy and the built environment

Circular economy is a very broad topic, and the terms and actions related to it are usually described by the context. There is not only one right definition for the circular economy, and there are subtle differences between definitions according to different parties. Kirchherr et al. (2023) made an analysis of 221 definitions for circular economy. According to the Ellen MacArthur foundation, at the core of the circular economy are three principles: (1) Eliminate waste and pollution, (2) Circulate products and materials and (3) Regenerate nature (What Is a Circular Economy? | Ellen MacArthur Foundation, n.d.-a). A circular economy can be defined as an economic model where products are used in a closed loop and the value of products is preserved. A completely closed loop, e.g., energy wise, is, by the laws of physics, impossible, but getting close to that is achievable.

The nature of regenerative and finite resources in the circular economy can be clarified through material flow model. Material flows can be separated into two cycles, technical (finite) and biological (regenerative). The material flow in a closed loop in a circular economy framework can be explained through a circular economy system diagram also known as the butterfly diagram (see Figure 3). In biological cycle renewable and plant-based resources are used, generated, and nutrients in organic waste can be returned to the biosphere through composting or anaerobic digestion. The technical cycle comprises human made products and materials such as plastics or metals. When examining Figure 3, the technical cycle (right side of image) has more loops compared to the biological cycle (left side of image). The smaller the cycle, the more the product can retain embedded value. The smaller the cycle, the fewer alterations are done to the product.



**Figure 3. Butterfly diagram by Ellen MacArthur Foundation. (The Butterfly Diagram: Visualising the Circular Economy, n.d.)**

In Figure 3 the most embedded value is in the action of sharing and in maintenance of the product. Next in hierarchy are reuse, refurbishment, and lastly recycling (Luebkehan & Fellow, 2016, pp. 16–17). Definitions for this stage vary a bit according to how many re-strategies are included but it is often referred to as the R-strategy or R-framework (Dokter et al., 2021). According to Potting et al (2007) even ten strategies can be included: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover.

Circular economy has gained importance in the agendas of policymakers, and it has been e.g., recognized as a strategy for sustainable growth, including in the built environment (Circular Economy Action Plan - European Commission, n.d.; Circular Economy Strategy - European Commission, n.d.). Examples for this are on EU level the Circular Economy Action Plan that is part of European Green Deal and in China the Chinese Circular Economy Promotion Law (Lieder and Rashid, 2016). Circular economy can also be seen as a strategy that addresses issues pointed out in section 2.2. It can be stated that reducing consumption and therefore economic growth is in the means of CE, which can be seen as a challenge in the current capitalistic economic model which goes hand in hand with linear economy model (take-make-waste). In a linear economy economic growth is based on consumption of products or goods. They are produced, consumed and after being used, they come to the end of their service life and are seen as waste that then will be placed to waste treatment plants. In circular economy economic growth is not dependent on consumption or the use of finite resources i.e., decoupling economic activity from the consumption of finite resources. (Luebkehan & Fellow, 2016, p. 10; What Is a Circular Economy? | Ellen MacArthur Foundation, n.d.-b)

Sustainability and the circular economy as concepts are frequently used in similar contexts, but the literature has not clearly defined their similarities and differences. As a result, their conceptual boundaries remain unclear, limiting the effectiveness of their application. Geissdoerfer et al. (2017) argue that a circular economy is a prerequisite to sustainability. They also mention that the concepts have different origins, goals, motivations, system prioritisations, institutionalisations, beneficiaries, timeframes, and perceptions of responsibilities. Most authors in their research emphasize the environmental performance improvements of the Circular Economy rather than considering all three dimensions of sustainability holistically, but this trend is also seen among some authors in the broader field of sustainability. (Geissdoerfer et al., 2017)

The circular economy has been criticized for a lack of definitions, plans and implementations. This is part of a question that at times is brought up, can circularity be a goal or a tool to achieve sustainability and staying within planetary boundaries, when the model still relies on economic growth. Many models also lack e.g., social fairness and socio-cultural aspects compared to the SDGs. (Corvellec et al., 2022; Kirchherr et al., 2023) Circular economy discourse has as well been presented having a technocratic framing (Niskanen et al., 2020).

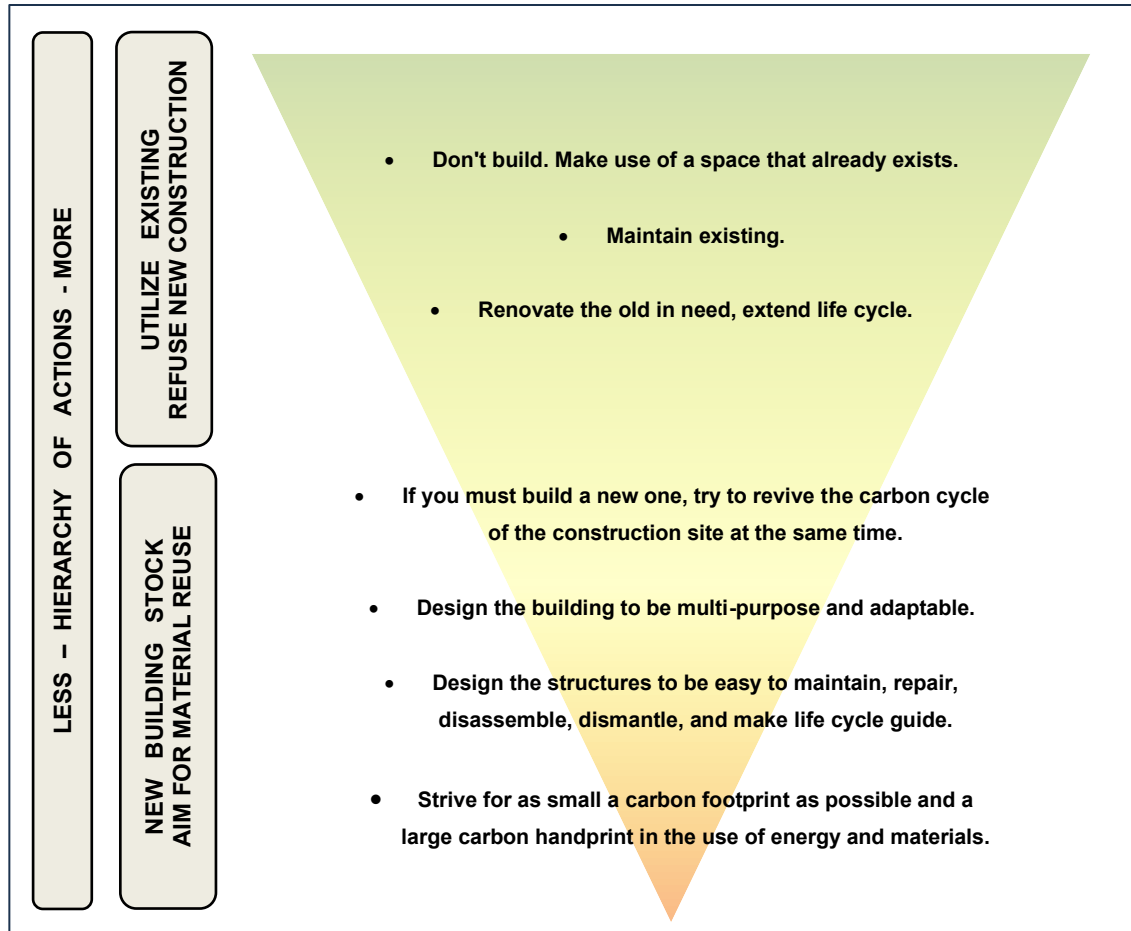
As described in section 2.2, the construction industry is a highly finite resource and energy consuming industry, and the construction and demolition of the built environment generate waste.

The shift towards a circular economy in the construction industry would have great impacts on the negative aspects described previously. Circular economy in the history of the environment is not a novel topic. The industry has been maintaining, reutilizing, upgrading and repurposing infrastructure and buildings for centuries (Luebkehan & Fellow, 2016, p. 79). As described previously, circular economy and sustainability overlap greatly, and in the built environment context the case is the same. Circular and sustainable construction have many similar goals. Circular economy can be seen as a means to achieve sustainability in the built environment sector. The most impressive actions that can be taken in the construction industry are to cut (finite) resource and energy consumption and reduce emissions. (Huttunen, 2021, p. 17) From the life cycle perspective the circular economy considers multiple uses and re-loops in the whole life cycle instead of one or two loops (Eberhardt et al., 2020).

Generally, it is considered that the best kind of circular economy is to take care of the existing building stock in a way no demolition is needed. Carbon emissions are one of the biggest negative factors in the construction industry. When examining a building's carbon footprint, the largest emissions come from energy use in the operational phase (operational emissions). This issue can be tackled with cleaner energy. Another large emission load (carbon peak) occurs in the initial phase of new construction from (mostly) production and (less) construction phase. Currently, the carbon emission payback time takes too much time because emissions should be reduced immediately. This effect can be reduced by extending the life cycle of existing building stock, e.g., by renovation and replacement. (Huttunen, 2021, p. 17) The long life cycle of existing structures and the high utilization rate of spaces are at the core of circular thinking. According to Kuitinen (2023) the most effective way to tackle carbon emissions in the built environment is through a hierarchy of actions which is presented in Figure 4. This can also be applied to sustainability framework in the built environment. The separation of biological and technical cycles and adding the R-strategy in the figure can act as an effective yet simple framework for actions in the construction industry. Actions that can be taken are firstly building preservation through life cycle extension (maintenance, repair, renovation, adaptive reuse/transformation, relocation), secondly component preservation, which means reuse of building parts, thirdly material preservation through making construction materials of recycled materials and lastly earthworks or energy production. In the case of materials and products, a similar process can be called R-strategy, which was explained earlier, or cascading. In that process a product is used in high level application, from where it moves to middle- and lower-level applications through reuse, reprocess, different levels of recycling and eventually the product moves to the recovery phase. Often, the lower the product goes in the cascade system, the more limited the usage option becomes for the system.

In the context of a demolition of a building or building a new one, certain strategies are to be considered to achieve circularity. In a circular economy, cities and buildings are seen as material banks. This thinking is called urban mining, and, in that process, raw material is recovered from urban waste streams. Circularity can be approached from a design perspective. Dokter et al.

(2021) and Moreno et al. (2016) have listed circular economy design approaches: Value retention (R-imperatives, R-strategy), Design for disassembly (DfD), Design for sustainability (DfS), Cradle to cradle (C2C), Ecodesign, Biomimicry, Product service systems for sustainability, Adaptive reuse, Design for repair and remanufacturing and Design for excellence (DfX).



**Figure 4. The compiled hierarchy of actions in BE according to Arup Circular Building Toolkit, Huttunen, 2021 and Kuittinen, 2023. (Circular Buildings Toolkit, n.d.; Huttunen, 2021; Kuittinen, 2023)**

## 2.4 Assessment in built environment

In general, assessment refers to a process of evaluating, measuring, or monitoring a chosen performance or quality. The process includes collecting and analysing data or information, and as a result, informed decisions or improvements can be made (Fink, 2015, p. 24). In any assessment a chosen method is used to achieve results. Methodological types are quantitative, qualitative and a mixed method that uses both types. The quantitative method involves numerical data and provides e.g., adequate results for comparisons, whereas qualitative method uses non-numerical information e.g., observations or answers from interviews, which then again gives information in detail about processes or phenomena. A mixed method tends to give the most comprehensive results (Bamberger & Rugh, 2012). An assessment process usually includes the

following stages: planning, data collecting, analysis, reporting, acting, and monitoring (Fink, 2015, p. 25). Terminology related to assessment processes is presented in Table 1.

In the built environment assessment can be related to various processes at different levels such as sustainability or circularity. The afore mentioned topics are broad, and to ease analysis and further, better informed evaluation or decision-making, it is common to split the topic into sub-topics. These sub-topics are then to be covered with an impact. (Bond & Morrison-Saunders, 2011) In the case of sustainability, the topic is often divided into sub-topics and impact categories: environmental impacts, economic impacts, and social impacts. Each of these topics can then be measured with an indicator which reflects e.g. GHG or toxicity level and can be given a numerical value. Impact assessment can be tied to e.g., SDGs. Different goals are measured with chosen impacts which then provide information on goals, improvement, or the basis for decision-making. Standardized assessment plays a critical role when considering sustainability or circularity and the system change. Assessment enhances transparency and accountability, especially when using standardized methods, for different stakeholders with evidence-based information.

**Table 1. Terminology for assessment process. (OECD, 2003; Sala et al., 2013, 2015; Waas et al., 2014)**

<b>Framework</b>	The rationale and structure for the integration of concepts, methodologies, methods, and tools
<b>Methodology</b>	Is a collection of individual characterisation methods, which together address the different environmental, economic, and social issues and the associated effect/impact
<b>Method</b>	A set of models, tools and indicators that enable the calculation of the values of indicators for a certain impact category
<b>Model</b>	The mathematical description of the system and it is used to calculate a particular indicator of the impact of environmental/social/economic interventions
<b>Tool</b>	The software, application, database supporting the analysis done by adopting a specific metho and the related models
<b>Indicator</b>	A measurable parameter, or a numerical value derived from such parameters, which highlights, provides information on, or maps out the state of a phenomenon, with a meaning reaching out beyond that directly associated with its value
<b>Impact</b>	Refers to long term changes that occur because of activity or program, reflect effectiveness of actions

## 3. METHODOLOGICAL BACKGROUND AND RESEARCH QUESTIONS

### 3.1 Methodological background

It has been stated that the built environment researchers work with broad boundaries with different methodologies and according to Knight & Turnbull (2008) use methods from across the spectrum of more well-defined disciplines such as mathematics, social natural and physical sciences as well as arts and humanities (Knight & Turnbull, 2008). Most of the books and articles in this review that are used as a reference for the methodological part are from medicine and healthcare research sector. It seems that the field is in a meaningful position in defining research methodology and far along with the analytical side of scientific methodology. Many guidebooks and guidelines are available for the healthcare sector e.g. 'How to do a systematic literature review in nursing: a step-by-step guide' (Bettany-Saltikov, 2012). Simultaneously, it was not easy to find research on the topic of scientific ways of doing research in built environment and even harder in the field of architecture. It also seemed common to use healthcare sector codes of practice for the methodological parts in the built environment research. Multiple papers from healthcare sector were used as references on the methodological section due to these reasons.

One reason to produce this research was to allow the writer to experience the process of doing scientific research and writing through conducting such a review and for the writer to gain knowledge on the matter itself. Considering the writer's minor experience in scientific research and writing and in the contents of the topic at the beginning of the process, a broader point of view at the beginning of the process was considered necessary and sensible.

What is common for different types of reviews in general is the process of search, evaluation, synthesis, and analysis of literature (*Start Here - Systematic Searching - Oppaat | Guides at Tampere University Library*, n.d.). Grant & Booth (2009) characterized fourteen review types in their review article 'A typology of reviews'. In the same paper they claim that what reviews have in common comes from the term 'review' itself. According to The Britannica Dictionary the term 'review' is defined as: 'an act of carefully looking at or examining the quality or condition of something or someone: examination or inspection'. Cambridge Dictionary defines the term as: 'to think again, the act of considering something again in order to make changes to it, give an opinion of it or study it'. What is undeclared in different types of reviews according to (Grant & Booth, 2009) is the variations in the processes and the level of precision in different review types meaning that the methodological aspects of the review types differ.

Another way of defining reviews is through the term of literature review, where reviews are divided into four categories: Narrative review, Systematic review, Rapid review, and Scoping review. The term literature review can be described as a general concept term and these review types can be gathered under this term. (*Doing a Systematic Review*, 2017, pp. 10–12) Sutton et al. (2019)

structure review types into seven families: Traditional Reviews, Systemic Reviews, Review of Reviews, Rapid Reviews, Qualitative Reviews, Mixed method Reviews, and Purpose specific Reviews. It is important to mention that labels and terminology overlap depending on the sources and vary by discipline, and the methodological side of reviews constantly evolves. This leads to the conclusion that whichever review type and associated method are being used, it is important to be logical -systematic- with the chosen review type, but this doesn't mean yet that they would be systematic reviews (Booth et al., 2016).

Defining features for a systematic review are transparency, replicability, and a comprehensive search approach (Sutton et al., 2019). What else is common for systematic reviews is a reporting guideline such as PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) (Sutton et al., 2019). Scoping reviews have a PRISMA based reporting guideline PRISMA-ScR (Tricco et al., 2018a). It was developed to provide a reporting guideline for this specific review type in knowledge synthesis (Tricco et al., 2018b). Scoping reviews have a broader approach compared to systematic reviews (Munn et al., 2018). What is common between a scoping review and a systematic review is that they both are rigorous and systematic in the transparency of the protocol that allows replicability (Grant & Booth, 2009). Peters et al. (2015) write that 'Whereas a typical systematic review aims to answer a specific question or series of questions according to a rigid set of a priori delimiting factors detailed in the protocol, scoping review will have a broader approach, generally with the aim of mapping literature and addressing a broader research question'. It is important to mention that in scoping reviews quality appraisal of the chosen studies is not typically done (Peters et al., 2015). What else is important to bring to light regarding scoping reviews, is that because there is no quality assessment, the sole existence of the chosen studies does not self-evidently mean that the studies can be used as the basis for conclusions (Grant & Booth, 2009).

Scoping review was chosen as the review type over systematic literature review due to the screening nature of the work. The stages of a scoping review will be defined more closely in the next section but in general they mostly follow systematic review stages which include 1. Defining the research question(s), 2. Protocol, 3. Developing a search strategy, 4. Applying inclusion and exclusion criteria, 5. Data extraction, 6. Charting the results and 7. Writing discussion and conclusions (Peters et al., 2015), (*Doing a Systematic Review*, 2017, p. 2,9), (Bettany-Saltikov, 2012, p. 7,9)

## 3.2 Defining research questions

The title of this review is: "Assessment methods of circularity in the built environment". The objective of this review is to examine whether there are assessment methods to evaluate circularity in the built environment in general, and if yes, what kind methods are used and where information gaps can be found.

The objective is vast and led to a preliminary study with the final pool of papers. A look on the subject was taken to verify the assumed starting point which was that assessment methods would

exist. This was done by examining whether assessment methods of circularity are researched and/or used in the built environment in general. Another aspect that was examined was whether the methods were purely theoretical or were the studied methods used in a case study. The outcomes of the preliminary study are included and described in the results section.

The main research question is: (1) 'What kind of methods are used to assess circular economy/circularity in the built environment?'. The question was formed at the very beginning of the process, and within the question is the assumption of the existence of circular assessment methods. The preliminary study was done due to this reason. Within the scope of the question, a look at metrics related to the assessment methods was also done to better understand how the assessment methods work and what they measure. Listing the metrics helps to clarify how the methods compare to one another in terms of their impacts.

The first research question led to two consecutive questions. Consecutive questions (2) and (3) were formed because there was a need to clarify how the methods were used. The second research question is: (2) 'In which levels are the methods used?'. At the beginning of the process, there was an assumption that circularity would be observed in physical form e.g., city, building, component, material. From the read material rose the aspect that the levels of circularity were layered and that methods were also used e.g., on systemic dimensions as well as physical dimensions. Ultimately, four different levels (micro, meso, macro and systemic) were identified and used as framework for the research question 2. Before identifying the level that the method was used on, it was mandatory to identify the scope or scopes of each paper, the object of research in each paper, which made it possible to see to what and how the selected methods were applied on.

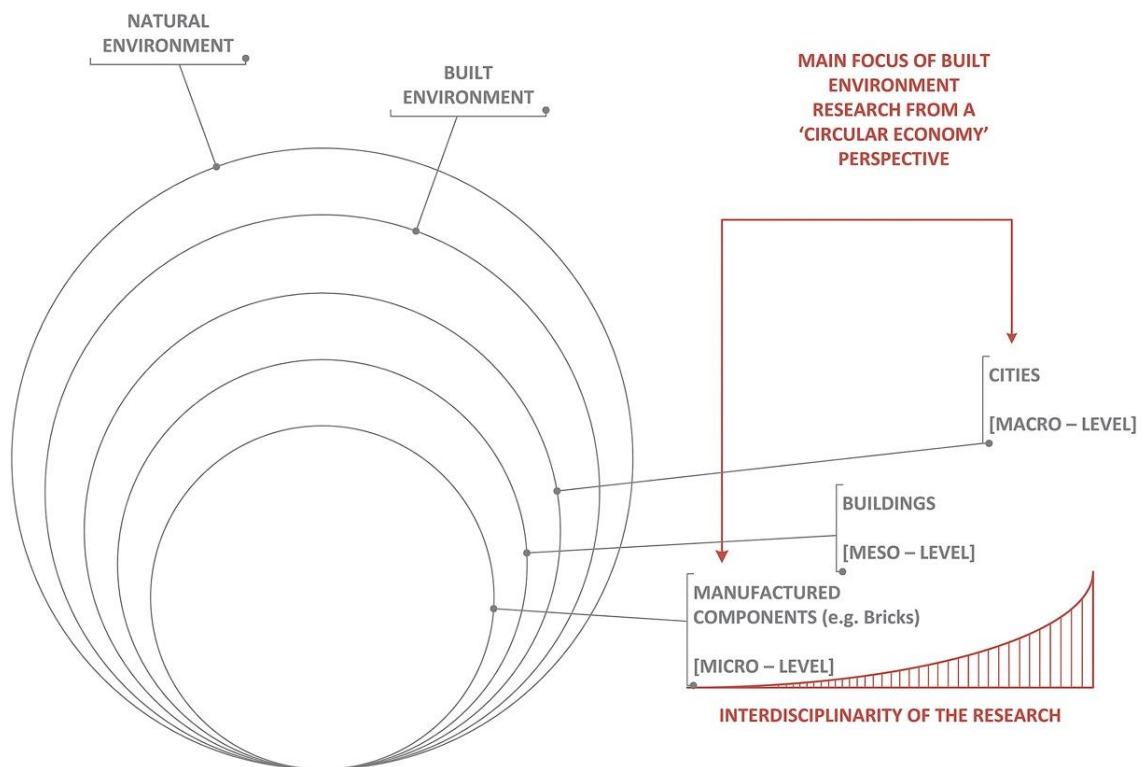
The third research question is: (3) 'Which life cycle stages are considered in circularity assessment?'. In this question the viewpoint is as to which life cycle stages are included in assessment according to EN 15978 and EN 15804 standards.

### **3.3 Research framework**

'Circular economy for the built environment: A research framework' by Pomponi & Moncaster has been a major source and reference when understanding approaches and entity of this topic (Pomponi & Moncaster, 2017). Their viewpoints support the common outlooks on circularity and sustainability in general. Our physical built environment can be divided into three levels: 'macro', 'meso' and 'micro', where cities and urban regions create macro level, meso level refers to buildings and micro level to building components. This is presented in Figure 5. Pomponi & Moncaster (2017) figure that interdisciplinarity of research in this topic broadens when moving from micro to macro level.

Another level, 'systemic level', was added to the framing system during the later screening process of the material, due to the emerged need. It became evident that the three first introduced

levels, that were only defined through physical features, were not sufficient and systemic level was included in the framing. In this study, the systemic level refers to policies and regulations.



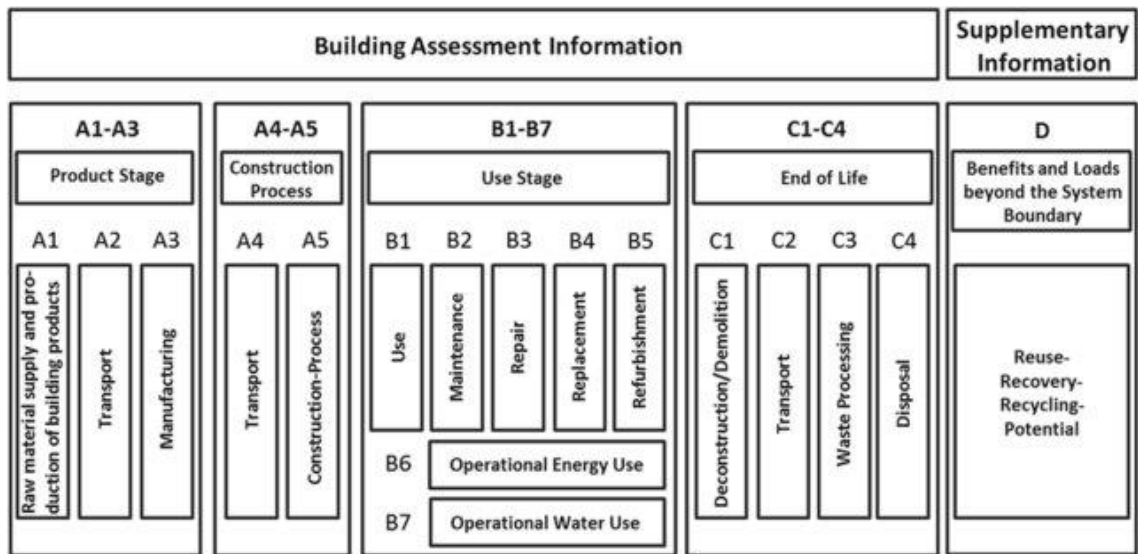
**Figure 5. Framing of the built environment research according to Pomponi & Moncaster (2017).**

Pomponi & Moncaster (2017) also present a frame of reference of six dimensions. They address that in addition to environment, society, and economy, in other words, the three pillars of sustainability, at least three other dimensions should be considered in built environment circularity. These are governmental, technological, and behavioural aspects that underline the interdisciplinary approach. The systemic level that was introduced before can be seen as an umbrella term that includes a governmental dimension and is partly behavioural as well.

Pomponi & Moncaster (2017) highlight that two things should be considered when framing research on circularity in buildings. First is that many of our tools for evaluating circularity focus on new buildings and not the existing building stock. With 60 to 90 years old building stock only focusing on new won't meet the requirements of lowering the use of virgin materials or lower carbon emission levels. Second is that buildings with many differently designed products and layers create a complex entity that is hard to manage from CE viewpoint.

'EN 15978:2011 Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method' and 'EN 15804:2012+A2:2019 - Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products' define Life Cycle Assessment (LCA) stages for construction projects in the construction

industry. Life cycle stages are presented in Figure 6. These standards have created a framework for the third research question.



**Figure 6. System boundaries according to EN 15804/EN 15978. Figure according to Achenbach et al. (2018)**

## 4. RESEARCH PROCESS

### 4.1 Search strategy

In this section the process of paper selection will be explained; how the evaluation of the selected papers will be done, what kind of framework will be used to do this and the process of data extraction, and furthermore, how the papers answer the research question. This work focuses on academic publications that study or propose methods, tools or approaches to assess circularity in the built environment.

As previously figured, scoping reviews are to be replicable through structure and transparency. The following sections will describe the methodological process and search protocol for developing a search strategy, applying inclusion and exclusion criteria, data extraction and charting of the results in detail. The process follows the Preferred Reporting Items for Systematic Reviews and Meta-analyses for scoping reviews, PRISMA-ScR. (Tricco et al., 2018b)

Academic publications were collected from the Scopus database with three categories of search concepts. Tampere University library's LibGuide for systematic searching was used as a reference for the formation of a search strategy (*Start Here - Systematic Searching - Oppaat | Guides at Tampere University Library*, n.d.). The concepts were formed based on the research questions. The first search category is 'assessment methods', the second is 'circular economy' and the third is 'built environment'. In these concept groups are listed synonyms and keywords regarding the topic. Table 1 presents in detail the keyword lists and the formation of the search string. The final search string applied to Scopus is presented in Table 3. It was formed from the three search strings and combined with the Boolean operator 'AND'. Asterisk (\*) was used to find all the derived terms from the keyword list as shown in Table 1 section C) Derived terms. A phrase was formed with quotation marks ("XXX").

Formulating the search string was done through an iterative process. Altogether 18 searches were done in Scopus during the autumn of 2022 before the final search early in 2023. Multiple searches were performed to see the spectrum of results and learn of search strategies. Also, some keyword synonyms were revised. The search string was designed to be focused and relevant to ensure a limited number of results that would be adequate for the extent of a thesis. Some search words were excluded from the search concepts due to the false orientation in the topic, for example 'CE' which in this context refers to 'circular economy' but skewed the pool of results into considering CE-marking. Another example that should be mentioned is the term 'life cycle' which accentuated search results strongly towards LCA and increased the paper number in total to hundreds. Next, the search terms were combined and the search string was put together. This is presented in Table 2. In Scopus the search string is formed in a way presented in Table 3. The exclusion criteria were added to the end of the search string, as it can be done this way in Scopus. The exclusion criteria will be explained in detail in the next section.

**Table 1. Search strategy.**

<b>A) Search concepts</b>		
<b>CONCEPT 1</b>	<b>CONCEPT 2</b>	<b>CONCEPT 3</b>
assessment methods	circular economy	built environment
<b>B) An extended keyword list</b>		
<b>CONCEPT 1</b>	<b>CONCEPT 2</b>	<b>CONCEPT 3</b>
<ul style="list-style-type: none"> <li>- assessment method</li> <li>- assessment system</li> <li>- assessment process</li> <li>- evaluation method</li> <li>- evaluation system</li> <li>- evaluation process</li> <li>- appraisal method</li> <li>- appraisal system</li> <li>- appraisal process</li> </ul>	<ul style="list-style-type: none"> <li>- circular economy</li> <li>- circularity</li> <li>- CE (won't be used due to possible misunderstanding between circular economy and CE-marking "<i>conformité européenne</i>")</li> <li>- life cycle (won't be used because decentralizes the search results)</li> <li>- circular design</li> </ul>	<ul style="list-style-type: none"> <li>- built environment</li> <li>- built habitat</li> <li>- building industry</li> <li>- building material</li> <li>- building design</li> <li>- building structure</li> <li>- architecture</li> <li>- construction sector</li> <li>- construction industry</li> <li>- building component</li> </ul>
<b>C) Derived terms</b>		
<b>CONCEPT 1</b>	<b>CONCEPT 2</b>	<b>CONCEPT 3</b>
<ul style="list-style-type: none"> <li>- assessment, -s</li> <li>- assessing</li> <li>- assessed</li> <li>- assessable</li> <li>- assessability</li> <li>⇒ <b>assess*</b></li> <li>-----</li> <li>- evaluation, -s</li> <li>- evaluating</li> <li>- evaluated</li> <li>- evaluable</li> <li>- evaluational</li> <li>- evaluability</li> <li>- evaluate</li> <li>⇒ <b>evalua*</b></li> <li>-----</li> <li>- appraisal, -s</li> <li>- appraising</li> <li>- appraised</li> <li>- appraisalment</li> <li>⇒ <b>apprais*</b></li> <li>-----</li> </ul>	<ul style="list-style-type: none"> <li>⇒ <b>circular economy</b></li> <li>-----</li> <li>⇒ <b>circularity</b></li> <li>-----</li> <li>⇒ <b>circular design</b></li> </ul>	<ul style="list-style-type: none"> <li>⇒ <b>built environment</b></li> <li>-----</li> <li>⇒ <b>built habitat</b></li> <li>-----</li> <li>- industry, -ies</li> <li>- industrial</li> <li>⇒ <b>building industr*</b></li> <li>-----</li> <li>⇒ <b>construction industr*</b></li> <li>-----</li> <li>- material, -s</li> <li>- materialistic</li> <li>⇒ <b>building material*</b></li> <li>-----</li> <li>⇒ <b>construction material</b></li> <li>-----</li> <li>⇒ <b>construction sector*</b></li> <li>-----</li> <li>⇒ <b>building design</b></li> <li>-----</li> <li>- structure, -s</li> <li>- structural</li> </ul>

- method, -s - methodology ⇒ <b>method*</b> ----- - system, -s ⇒ <b>system*</b> ----- - process, -es - processing ⇒ <b>process*</b>		⇒ <b>building structur*</b> ----- - architecture - architectural - architectonic - architect, -s ⇒ <b>architect*</b>
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**Table 2. Search string.**

"assess* method*" OR "assess* system*" OR "assess* process*" OR "evalua* method*" OR "evalua* system*" OR "evalua* process*" OR "apprais* method*" OR "apprais* system*" OR "apprais* process"	AND	"circular economy" OR circularity OR "circular* design"	AND	"built environment" OR "built habitat" OR "building industr*" OR "construction sector*" OR "construction industr*" OR "building design" OR "architect*" OR "building material*" OR "building structur*" OR "construction sector*" OR "construction industr*"
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**Table 3. Final search string used in Scopus.**

<pre>( TITLE-ABS-KEY ( "assess* method*" OR "assess* system*" OR "assess* process*" OR "evalua* method*" OR "evalua* system*" OR "evalua* process*" OR "apprais* method*" OR "apprais* system*" OR "apprais* process" ) AND TITLE-ABS-KEY ( "circular economy" OR circularity OR "circular* design" ) AND TITLE-ABS-KEY ( "built environment" OR "built habitat" OR "building industr*" OR "construction sector*" OR "construction industr*" OR "building design" OR "architect*" OR "building material*" OR "building structur*" ) )  AND PUBYEAR &gt; 1999 AND ( LIMIT-TO ( DOCTYPE , "ar" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) )</pre>
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In any systematic review it is important to explain the rationale of exclusion criteria to ensure the replicability of the search. In this study the exclusion criteria can be divided into two sections,

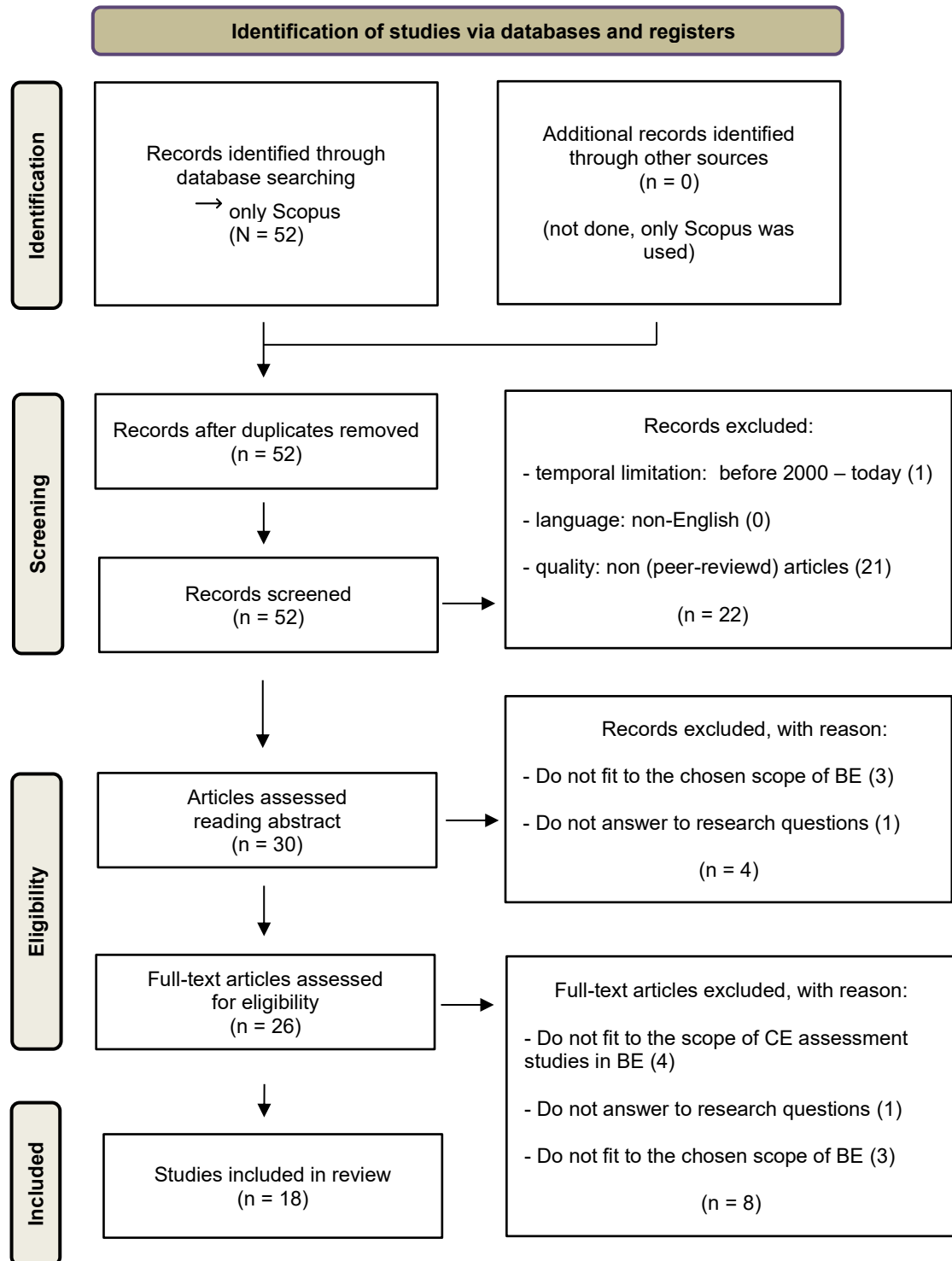
where the first one is factual/declaratory and the second one is thematic. All exclusion criteria are listed in Table 4.

**Table 4. Eligibility criteria.**

<p>A. Factual exclusion rationale:</p> <ul style="list-style-type: none"> <li>• Temporal limitation</li> <li>• The scientific quality of the content (book, peer-reviewed article, magazine article etc.)</li> <li>• The database</li> <li>• Grey literature</li> <li>• Removal of duplicates</li> <li>• Language</li> <li>• Studies with full text available</li> </ul> <p>B. Thematic manual exclusion from full text articles</p> <ul style="list-style-type: none"> <li>• Problem statement <ul style="list-style-type: none"> <li>○ the study must assess or review circular economy methods or approaches in built environment in systemic, macro, meso or micro level (civil engineer design-based infrastructure not included, e.g. bridges)</li> <li>○ the study must handle CE on the levels of material or system</li> </ul> </li> <li>• Research questions</li> </ul>
---

Temporal limitations for the search were selected from years 2000 until January 2023, when the final search was conducted. The limitation was set to these boundaries to view the temporal development of the studied subject. The scientific quality of the content for this work was limited to peer-reviewed articles to achieve comparable material. Because this review is a master's thesis, not an article to be published, nor part of any scientific research team, the scope of the search was abridged to be done in only one database. In this case it was chosen to be Scopus. No gray literature was included in the search for the same reason as mentioned previously. Any duplicates were not present, since only one database (Scopus) was used. All papers were required to be written in English with full text available. On the thematic side, all papers were given a qualitative read-through, first by title and abstract base. A thorough thematic read through was done after, with an exclusion viewpoint, to make sure that the papers from search were relevant for the study.

The search decision flowchart (PRISMA-ScR) is presented in Figure 7 with the four typical steps for the PRISMA flow diagram, which presents the stages of identification, screening, eligibility, and number of included studies (Moher et al., 2010) (Peters et al., 2015). This diagram illustrates the paper selection process in total.



**Figure 7. Summary of the search process in a flow diagram according to Preferred Reporting Items for Systematic Reviews (PRISMA) for the scoping review process (PRISMA, n.d.; Tricco et al., 2018b).**

## 4.2 Data extraction

The preliminary data extraction form was formed by the author, and according to (Peters et al., 2015) and additional charting items were added after reading the selected papers fully. Extraction

items are presented in Table 5. More data items were added to the list later because of the iterative learning process of this work. The data was collected into a file in Excel. The data extraction form functions as a review framework that categorizes the inventoried data.

**Table 5. Extraction fields.**

1. ID no
2. Authors
3. Year of publications
4. Name of the study
5. University / Affiliation
6. Country of origin (based on first listed affiliation)
7. Continent
8. Source of origin
9. Aims/purpose of the study
10. Topic / Concept
11. Research question of the study
12. How research was conducted / Study design of the paper
13. Included case study?
14. Study scope / samples / functional unit / to what were the methods or tools used for?
15. Level (systemic, macro, meso, micro)
16. How are outcomes measured in paper?
17. To what were the used methods applied for (study scope)?
18. What kind of assessment methods are used to assess circular economy/circularity in the built environment?
19. Definitions of the methods
20. What was measured with method/tool (eg. impact)?
21. Impact category and possible unit
22. What parties / stakeholders were included in the process? / What aspects are regarded (environmental, societal, economic, decision making)
23. For what stage in the life cycle is the method used for / Is the studied subject new or used?
  - a. Life cycle stages categorized if applicable
24. Key findings that relate to the review question
25. General good points
26. Own comments

The search firstly resulted in 52 publications, and from that pool 18 papers met the set criteria and were included in the review. The included papers are listed in Table 6. 22 of the original search results did not meet the set criteria. 21 of the search results were conference papers and were for that reason excluded from the final set of papers. One paper was published before year 2000 and was therefore excluded from the final set of papers. From the set of 30 papers 4 (Avallone, 2021; Coenen et al., 2021; Nicolini, 2022; Hahldakis, 2020) were excluded based on title and abstract. The rest were fully read and out of those 8 more articles were excluded.

Altogether 12 articles were excluded for various reasons concerning the contents of the articles, leaving 18 papers to form the final group of papers. Reasons of exclusion are briefly explained in the Table 7.

**Table 6. Included articles.**

Name of the included article	Authors	Year
Circular economy strategies in eight historic port cities: Criteria and indicators towards a circular city assessment framework	Gravagnuolo, A., Angrisano, M., Girard, L.F.	2019
Lean deconstruction approach for buildings demolition processes using BIM	Marzouk, M., Elmaraghy, A., Voordijk, H.	2019
Service life planning and durability in the context of circular economy assessments — Initial aspects for review	Bourke, K., Kyle, B.	2019
Human health and well-being in relation to circular and flexible infill design: Assessment criteria on the operational level	Geldermans, B., Tenpierik, M., Luscuere, P.	2019
Comparison of environmental assessment methods when reusing building components: A case study	De Wolf, C., Hoxha, E., Fivet, C.	2020
Development of a life cycle assessment allocation approach for circular economy in the built environment	Eberhardt, L.C.M., van Stijn, A., Rasmussen, F.N., Birkved, M., Birgisdottir, H.	2020
A circular economy life cycle costing model (CE-LCC) for building components	Wouterszoon Jansen, B., van Stijn, A., Gruis, V., van Bortel, G.	2020
A Circular Economy Life Cycle Assessment (CE-LCA) model for building components	van Stijn, A., Malabi Eberhardt, L.C., Wouterszoon Jansen, B., Meijer, A.	2021
Circular economy in the construction sector: advancing environmental performance through systemic and holistic thinking	Sparrevik, M., de Boer, L., Michelsen, O., (...), Knudson, H., Fet, A.M.	2021
Assessment methods for evaluating circular economy projects in construction: a review of available tools	Lovrenčić Butković, L., Mihić, M., Sigmund, Z.	2021
Building circularity assessment in the architecture, engineering, and construction industry: A new framework	Zhang, N., Han, Q., de Vries, B.	2021
Regional circular economy of building materials: Environmental and economic assessment combining Material Flow Analysis, Input-Output Analyses, and Life Cycle Assessment	Meglin, R., Kytzia, S., Habert, G.	2022
Environmental design guidelines for circular building components based on LCA and MFA: Lessons from the circular kitchen and renovation façade	van Stijn, A., Eberhardt, L.C.M., Wouterszoon Jansen, B., Meijer, A.	2022
Human Toxicological Impacts in Life Cycle Assessment of Circular Economy of the Built Environment: A Case Study of Denmark	Egemose, C.W., Bastien, D., Fretté, X., Birkved, M., Sohn, J.L.	2022
Potentiality of earth-based mortar containing bamboo particles for GHG emissions reduction	Paiva, R.D.L.M., Caldas, L.R., Martins, A.P.D.S., Toledo Filho, R.D.	2022
Circular alternatives in the construction industry: An environmental performance assessment of sisal fiber-reinforced composites	Santos, G.Z.B.D., Caldas, L.R., Melo Filho, J.D.A., (...), Rafael, S.I.M., Marques da Silva, N.	2022
Recyclability assessment at the building design stage based on statistical entropy: A case study on timber and concrete building	Roithner, C., Cencic, O., Honic, M., Rechberger, H.	2022
Integrated decision support for embodied impact assessment of circular and bio-based building components	Kayaçetin, N.C., Verdoodt, S., Lefevre, L., Versele, A.	2023

**Table 7. Excluded articles with reasonings.**

<b>Articles assessed reading abstract (4)</b>		
<b>Do not fit to the chosen levels of BE (3)</b>		
Assessing the role and use of recycled aggregates in the sustainable management of construction and demolition waste via a mini-review and a case study	Hahladakis et al. (2020)	The paper studied how the proposed method applies to a recycled aggregate
Development of a bridge circularity assessment framework to promote resource efficiency in infrastructure projects	Coenen et al. (2021)	The paper presented research of circularity in infrastructure, specifically bridges
The Circularity of MSW in Urban Landscapes: An Evaluation Method for a Sustainable System Implementation	Nicolini (2022)	The paper studied waste management not related to construction industry
<b>Do not answer to research questions (1)</b>		
On the relations between landscape and production the case study of rufoli in Salerno	Avallone (2021)	The paper did not study nor focus on circular methods or evaluation of those criteria
<b>Full-text articles assessed for eligibility (8)</b>		
<b>Do not fit to the scope of CE assessment studies in BE (4)</b>		
Carbon emission reduction in prefabrication construction during materialization stage: A BIM-based life-cycle assessment approach	Hao et al. (2020)	The paper did not consider circularity in the carbon emission reduction and LCA studies
Coffee biowaste valorisation within circular economy: an evaluation method of spent coffee grounds potentials for mortar production	La Scalia et al. (2021)	The paper did not consider assessment methods that could showcase the circularity of the product
How to Monitor and Evaluate Quality in Adaptive Heritage Reuse Projects from a Well-Being Perspective: A Proposal for a Dashboard Model of Indicators to Support Promoters	Dabbene et al. (2022)	The paper had a perspective of community well-being and proposed a framework to evaluate interventions, but not from circular viewpoint
Building energy retrofit-as-a-service: a Total Value of Ownership assessment methodology to support whole life-cycle building circularity and decarbonisation	Azcarate-Aguerre et al. (2022)	The paper studied an evaluation method for finance in construction, but it did not evaluate circularity
<b>Do not answer to research questions (1)</b>		
Multi-criteria decision making for sustainability and value assessment in early PSS design	Bertoni (2019)	The paper did not correspond to the research questions
<b>Do not fit to the chosen levels of BE (3)</b>		
A modular design strategy considering sustainability and supplier selection	Inoue et al. (2020)	The paper studied how the proposed method applies to a PC laptop design
Environmental impacts of wooden, plastic, and wood-polymer composite pallet: a life cycle assessment approach	Khan et al. (2021)	The paper's study scope and assessment went off topic from this research
Aiming for bullseye: a novel gameplan for circular economy in the construction industry	Zandee et al. (2022)	The paper did not correspond to the research questions

## 5. RESULTS

### 5.1 Preliminary view of included studies

The analysis of the reviewed articles is presented in the following sections. The first general attributes of the final pool of papers are presented and later classification according to the original research questions.

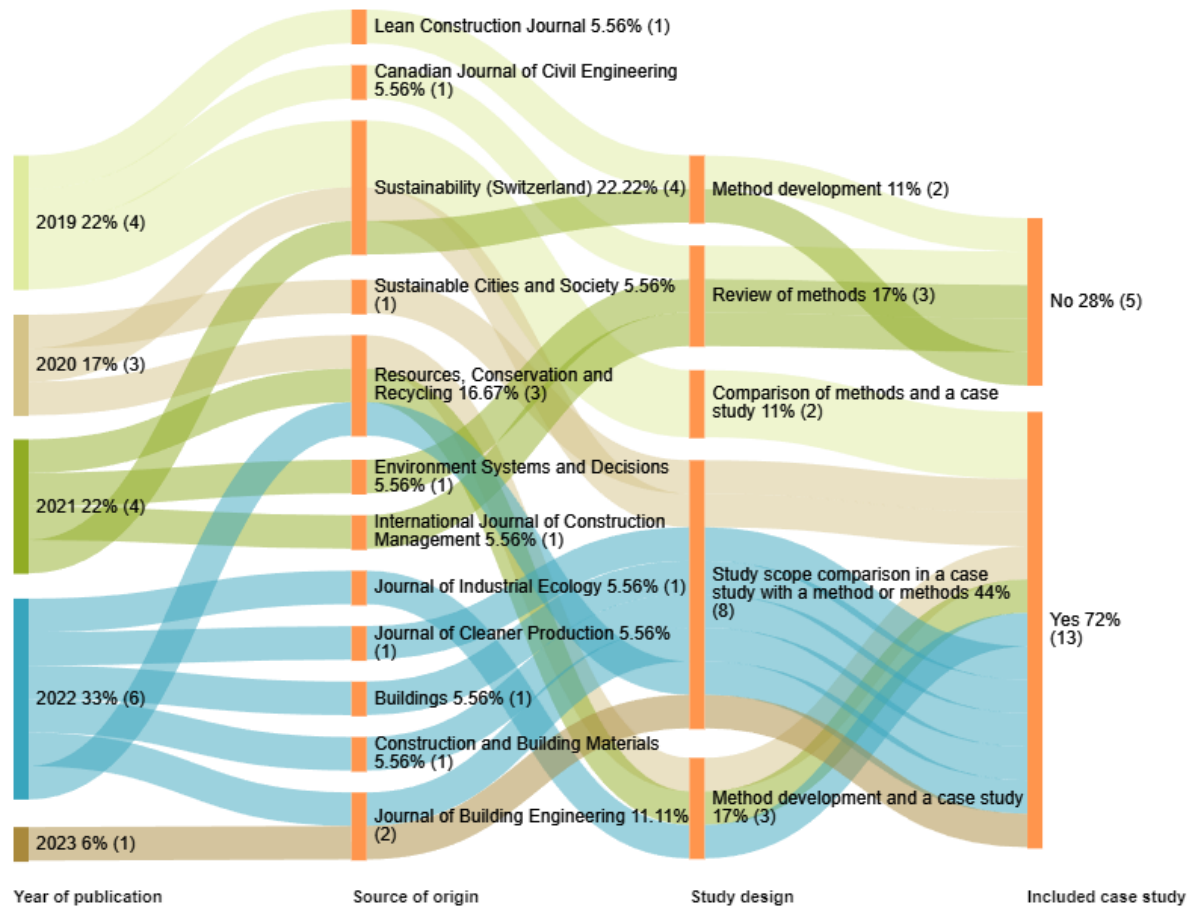
A preliminary view on the subject was done, and in it was studied whether assessment methods of circularity are researched and used in the built environment in general. This supposition was verified by the papers that were included in the thesis. Andersen et al. (2022) have studied circularity in built environment from Life cycle assessment viewpoint. All papers that were included in the final pool of papers studied, considered, reviewed, or used circular assessment methods, depending on the study design. It can be stated that circularity assessment in built environment research has a basis. Circularity in the built environment has gained momentum within the last decade, and according to multiple papers (Dokter et al., 2021; González et al., 2021; Lindgreen et al., 2020; Mhatre et al., 2021; Ossio et al., 2023; Pomponi & Moncaster, 2017) there is a growing need for further research on the topic. Most of the included papers recommended combining research with the practical side of the built environment. On top of research, many methods, such as LCA and MFA, can be stated to be widely used in the construction industry.

### 5.2 General attributes

The included papers appear in a great variety of journals. 4 papers out of the final pool of 18 papers were published in Sustainability (Switzerland), 3 in Resources, Conservation and Recycle, 2 in Journal of Building Engineering and rest of the papers were published in various publications as presented in Figure 8. The novelty of the topic can be noted from the same figure. The temporal scope of the search was set between years 2000 and 2022 and all the included papers were published year 2019 or later (2019 n = 4, 2020 n = 3, 2021 n = 4, 2022 n = 8). The trend of growing interest in circularity and assessment tools have been noted in some other reviews (Andersen et al., 2022; Lindgreen et al., 2020; Lovrenčić Butković et al., 2023). A slight increasing trend can also be noted with the number of published documents in relation to the publishing years disclosing the topicality of the subject, which would support previous conclusion, but this should be viewed critically due to the small number of samplings in this work.

The methodology of the papers was studied through categorization. That was done by going through the papers' study designs and then dividing the papers into categories by the study design models that were found. Five different study designs were found: Method development and a case study (n = 3, 17%), Comparison of methods and a case study (n = 2, 11%), Review of methods (n = 3, 17%), Method development (n = 2, 11%) and Study scope comparison in a case

study with a method or methods ( $n = 8, 44\%$ ). Distribution of publication year, journals, study designs and information of case studies are presented in Figure 8.



**Figure 8. General attributes.**

Altogether 13 papers included case studies, and a bit less than a third ( $n = 5$ ) of the studied papers did not include a case study (see Figure 8). Figure 8 presents general attributes of the papers such as year of publication, source of origin, study design and whether they included a case study. None of the papers, that involved a case study stated that research was done in collaboration with a property developer or construction company or such, or that there would have been interest for the process or results from the practician side of the construction industry. Therefore, it cannot be unequivocally stated that CE assessment methods are used in practice through the material studied.

When looking at the spatial trends (see Table 8) of the pool of papers, only 3 of the 18 papers were conducted outside of Europe (South America,  $n = 2$ ; Africa,  $n = 1$ ). The location was defined by the main author's affiliation showcased in selected papers. It is interesting that no publications that were published in North America, Oceania or Asia came up. North America (6%), Asia (9%) and Oceania (5%) are presented in Andersen et al. (2022) review 'Life Cycle Assessments of Circular Economy in the Built Environment'. Also, in Lindgreen et al. (2020) review 'A critical

review of academic approaches, methods and tools to assess circular economy at the micro level' previously mentioned continents are presented, even if their study does not focus only on built environment. Like in previously mentioned reviews, also in this review, most studies were conducted in Europe. In this review the most represented country was The Netherlands (n = 6), followed by Brazil, Denmark, and Switzerland (n = 2, each) and other papers represented countries of the United Kingdom, Norway, Italy, Croatia, Belgium, Austria, and Egypt (n = 1, each).

**Table 8. Spatial trends with continent, country of main author and paper authors.**

Continent (no. of papers)	Country according to the main author based on first listed affiliation (no. of papers)	Paper authors (publication year)
Africa (1)	Egypt (1)	Marzouk et al. (2019)
Europe (15)	the Netherlands (5)	Geldermans et al. (2019)
		Wouterszoon Jansen et al. (2020)
		van Stijn et al. (2021)
		Zhang et al. (2021)
		van Stijn et al. (2022)
	Switzerland (2)	De Wolf et al. (2020)
		Meglin et al. (2022)
	Denmark (2)	Eberhardt et al. (2020)
		Egemose et al. (2022)
	the United Kingdom (1)	Bourke et al. (2019)
	Norway (1)	Sparrevik et al. (2021)
	Italy (1)	Gravagnuolo et al. (2019)
	Croatia (1)	Lovrenčić Butković et al. (2021)
Belgium (1)	Kayaçetin et al (2023)	
Austria (1)	Roithner et al. (2022)	
South America (2)	Brazil (2)	Paiva et al. (2022)
		Santos et al. (2022)

### 5.3 Descriptive perspective

The first research question was 'What kind of methods are used to assess circular economy/circularity in the built environment?' Table 9 presents the distribution of assessment methods that were used in each paper and additionally the study scope and level. Study scope refers to items to which the assessment methods were applied on, and the level refers to how the study scope was categorized.

**Table 9. Assessment methods, study scope, and level.**

Study	Study scope	Level				Assessment methods or tools used or studied
		Micro	Meso	Macro	Systemic	
Gravagnuolo et al., 2019	Spatial territorial dimension / Urban metabolism assessment			X		1. Flow analysis (MFA) 2. Energy assessment 3. Foot-prints 4. Input-output analysis (IOA) 5. Network analysis 6. Life cycle assessment (LCA)
De Wolf et al., 2020	K.118 building exterior walls, floors, roof, intermediate floors, interior walls, fire protection, windows	X				1. The cut-off method /100:0 method (BSI, 2008) 2. End-of-life (EoL) method , 0:100 method (BSI, 2008) 3. Distributed Allocation Method (DAM) 4. European Commission Environmental Footprint (EC EF) 5. Degressive Method 6. SIA 2032
Eberhardt et al., 2020	A concrete column, a timber column, a recyclable roof felt, a window	X				1. EN 15804/15978 cut-off approach / 100:0 method 2. Circular Footprint Formula (CFF) 3. 50:50 approach 4. Linearly degressive (LD) approach
Wouterszoon et al., 2020	The circular kitchen CIK, Building component	X				1. Circular Economy Life-Cycle Costing (CE-LCC)
van Stijn et al., 2021	The circular kitchen CIK, Building component	X				1. Circular Economy Life-Cycle Assessment (CE-LCA)
Marzouk et al., 2019	Building component	X				1. Building Information Model (BIM) 2. Lean Principles
Meglin et al., 2022	Regional level			X		1. Integrated Assessment Model (IAM) (Material Flow Analysis (MFA), Life Cycle Assessment (LCA), Input-Output Analysis (IOA))
Sparrevik et al., 2021	Building component, building, systemic	X	X		X	1. Environmental product declarations (EPD) 2. Life Cycle Assessment (LCA) 3. Building certifications (LEED, Breeam) 4. policies, standards, legislation, regulations
Bourke et al., 2019	Building, building components	X			X	1. Techniques of Life Cycle Costing (LCC) 2. Life Cycle Assessment (LCA) 3. Social sustainability assessment CEN 15643 4. Service Life Planning (ISO 15686) 5. ISO 14000 series, in particular ISO 14040 (ISO 14040 2006) 6. ISO 20887 "Design for disassembly and adaptability of buildings"
Lovrenčić Butković et al., 2021	Assessment methods	X			X	1. Life cycle assessment (LCA) 2. Life cycle costing (LCC) 3. Cost benefit analysis (CBA)
Geldermans et al., 2019	Partition walls	X			X	1. Cradle to Cradle Certified™ (version 3.1) (C2C Certified) 2. Pre-Returnable Procurement® tool (version 3.1) (PRP) 3. WELL Building Standard™ (version 2)
Zhang et al., 2021	Building		X			1. Material flow model analysis (MFMA) 2. New Building circularity material passport (BCMP) 3. Building circularity calculation method (BCCM)
van Stijn et al., 2022	Kitchen, renovation façade	X				1. Material Flow Analysis (MFA) 2. Multi-cycle Life Cycle Assessment (LCA)
Egemose et al., 2022	Recycled wood, recycled concrete	X				1. Life Cycle Assessment (LCA)
Paiva et al., 2022	Bamboo mortar, mortar	X				1. Life Cycle Assessment (LCA)
Santos et al., 2022	Portland cement matrix composite, sludge composite	X				1. ReCiPe 2016 Midpoint/Endpoint 2. EN 15804 methods (EPD)
Roithner et al., 2022	Timber building, concrete building (External wall, External wall ground floor, Flat roof, Slab against outdoor air, Slab 1. floor, Slab 2. floor, Doors, Windows)	X	X			1. Relative product-inherent recyclability assessment (RPR)
Kayaçetin et al., 2023	Front façade, Side façade, Internal walls, Inclined roof, Floor, Floor on soil, Building	X	X			1. Life Cycle Assessment (LCA) 2. Circular Built tool

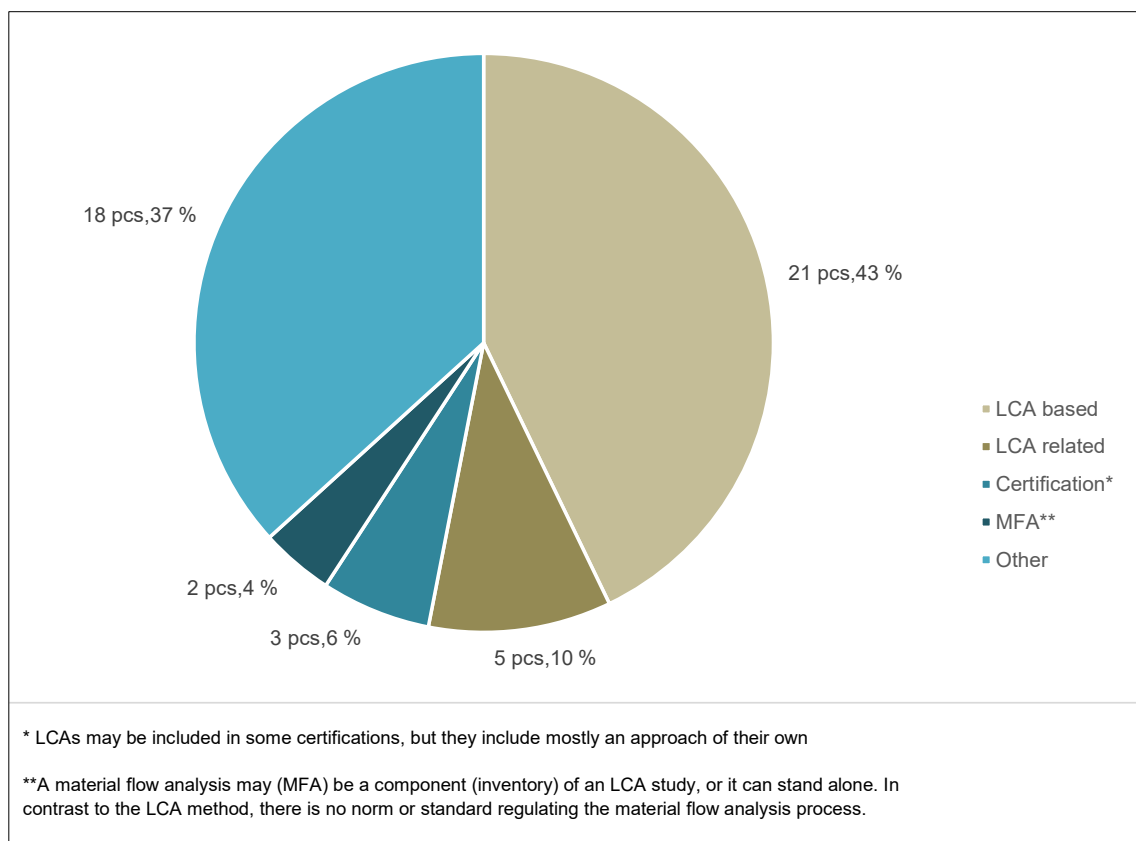
The papers' study scopes were categorized by the scaling system, which was formed by the base of research framework. The used scaling system consists of four levels: micro (components, materials, building parts), meso (buildings), macro (city, region), and systemic (policies, standards, legislation, regulations). Altogether, 49 assessment methods or tools were collected from 18 papers, and they are presented in Table 9.

The stages of Life Cycle Assessment (LCA) are explained in the ISO 14040 and ISO 14044 standards. These standards provide a detailed framework and guidelines for conducting an LCA. (European Standard, 2011, European Standard, 2012) In many papers, the reason for using LCA-based approaches is a consequence of the standardization of the LCA process (Eberhardt et al., 2020; De Wolf et al., 2020; van Stijn et al., 2021; Santos et al., 2022; Paiva et al., 2022; Egemose et al., 2022). All the papers that included only LCA based methods used these methods on micro scale. This underlines that the entirety of a building is formed through components, and the components can be assessed through a standardized LCA process. The whole of a building's life cycle is challenging to measure especially when dealing with multi-cycle approaches. Papers that expressed their scale focus on meso (building) level draw building circularity rates by synthesising information from materials and components used in case study buildings. The methods or methodologies listed in Table 9 are as presented in the search material. This can generate overlapping between terms and needs to be considered in comparisons of methods. Something can be said about differences between methods and methodologies. The terms are used in an inconsistent manner between papers and are dependent on the approach the papers have. It could be stated that the used calculation method is often called methodology, method then refers to a known or standardized method such as LCA and a tool refers to a combination of methods such as Breeam.

Other than LCA-based methodological approaches were used in 18 different assessment methods, see Table 9. This group of assessment methods appear in great variety. Figure 9 shows the connection of categorized assessment methods to existing assessment methodologies. 21 (43%) of the methods were LCA based, which means that they used or developed standardised LCA methodology. Five (10%) methods were categorized as LCA-related (Input-output analysis, IAM, variations of LCC). Almost half of the collected methods (23 pc, 47%) were categorized as other than LCA based. Three approaches were recognized as standardized certifications, which included four different certification types: LEED, Breeam, Cradle to Cradle Certified™ and WELL Building Standard™. Methods related to LCA are Life Cycle Costing (LCC) (n = 3) and Input-Output Analysis (IOA) (n = 2). Two assessment methods were recognized as commonly accepted Material Flow Analysis.

Altogether, five papers of the search pool included method development. All the method development approaches were in some connection to existing methodologies. Three of the approaches were connected or related to LCA or MFA. Two studies of those were connected by 'Circular Kitchen' CIK-concept (van Stijn et al., 2021; Wouterszoon Jansen et al., 2020), and they developed LCA and LCC techniques to meet the requirements for CE products. One approach

(Meglin et al., 2022) created an Integrated Assessment Model (IAM) with the combination of Material Flow Analysis (MFA), Life Cycle Assessment (LCA) and Input-Output Analysis (IOA). Two approaches of method development could be seen as novel with one (Marzouk et al., 2019) combining Lean principles and Building Information Modelling and the other (Zhang et al., 2021) creating a new framework for evaluating building circularity. Building circularity is evaluated with the new Material flow model analysis (MFMA), new Building circularity material passport (BCMP) and new Building circularity calculation method (BCCM). LCA and LCC (Life cycle costing) methodology is though used in the BCCM integrated assessment method. According to Zhang et al. (2021) "The building circularity calculation method follows the proposed material flow model, which contains three cycles: the technical cycle, the environmental cycle, and the economic cycle (i.e., the social cycle is left out in this paper). ... The calculations of the environmental cycle and economic cycle are based on existing LCA and LCC research". With the former the innovation lies in with assessment of existing building deconstructability and finding 'high recovery potential' in building elements. With the latter approach the novelty lies in the broad way of combining circularity assessment.



**Figure 9. Distribution of connections to existing methodologies.**

It can be stated that the existing methodologies have a very strong ground in assessing circularity and especially LCA-based methodology. This can be seen as a good thing because many of the aforementioned methodologies are subject to standardisation, which enables the methods to be introduced quickly for different operators and products. As many papers mentioned, this was the

reason for wanting to use existing methodologies. Another aspect to consider with the existing methodologies is, are they adequate to measure circularity.

As described in the beginning, circularity is an extensive and complex subject, and it is essential to separate the topic according to layers of significance. Within the scope of the first research question, a look at metrics related to the assessment methods was also done to better understand how the assessment methods work and what they measure. Metrics were listed to clarify how the methods compare to one another in terms of their impacts. Metrics and impacts are presented as the data given in the papers.

Table 10 shows which indicators were chosen to be used with each method according to different papers, and an impact categorisation was done according to the indicators. The clear impact categories that arose from the materials were 'Environmental' and 'Economic' approaches. A 'Parallel' category was created for integrated assessment methods that included multiple and parallel sub-indicators, and their aim was to create a common factor or indicator by combining or summing up the sub-indicators or factors. Additionally, a 'Not defined' category was created for such approaches where the papers did not clearly describe how the method was used, even in cases where the method was known, and the impacts and indicators could have been deduced.

28 assessment methods (60.9%) fell under 'Environmental impact category', four under 'Economical' (8.7%), eight under 'Parallel' (17.4%), and six under 'Not defined' (13.0%) of the 46 methods listed in Table 10. Impacts under Environmental impact category were most used (n = 16). Environmental impacts in five cases were further defined to mean global warming, ozone depletion, photochemical ozone formation, acidification, eutrophication, mineral and fossil resource depletion, and non-fossil resource depletion. Global warming potential singly was second used (n = 6), greenhouse gas emissions singly were third used (n = 5) and toxicological footprint was used as an indicator once when evaluating circularity in the built environment (n = 1). Economic impact and costs were used as indicators in four methods. Three methods were certifications (Cradle to Cradle Certified™, WELL Building Standard™, Circular Built tool) with grading-based evaluation, and in each the grading is tied up to the generated certification system. Three methods aim to describe recyclability or circularity potential with multiple sub-indicators. Circular city assessment methods used by Gravagnuolo et al. (2019) were not described in detail and were therefore categorized as 'Not defined'.

The second research question was 'In which levels are the methods used?'. Study, study scope, level and relation to assessment methods is presented in Table 9. 14 papers out of 18 (77.8%) studied methods on the micro level, which was therefore the most studied level in the categorization. It can be stated therefore that building components and materials were the most assessed study scopes. Meso and systemic levels both were studied in four papers, making buildings and systemic dimensions second most assessed scopes. Only two papers (Gravagnuolo et al., 2019, Meglin et al., 2022) studied assessment methods on a macro scale with study scopes 'spatial territorial dimension' and 'regional level'. This level was hence the least studied.

**Table 10. Impact categories, indicators, and methods.**

Impact category	What was measured (indicator)? / unit if given in material	Assessment methods or tools used or studied
Environmental	Global Warming Potential (GWP) / kg CO <sub>2</sub> eq/unit	The cut-off method /100:0 method (BSI, 2008)
		End-of-life (EoL) method , 0:100 method (BSI, 2008)
		Distributed Allocation Method (DAM)
		European Commission Environmental Footprint (EC EF)
		Degressive Method
	Greenhouse gas emissions (GHG)	SIA 2032
		EN 15804/15978 cut-off approach / 100:0 method
		Circular Footprint Formula (CFF)
		50:50 approach
	Environmental impact (Not defined further in the material)	Linearly degressive (LD) approach
		Environmental product declarations (EPD)
		Life Cycle Assessment (LCA)
	Environmental impacts (Not defined further in the material)	Building certifications (LEED, Breeam)
		Policies, standards, legislation, regulations
		Life Cycle Assessment (LCA)
Social sustainability assessment CEN 15643		
Environmental impact (Global warming, Stratospheric ozone depletion, Ionizing radiation, Ozone formation, Human health, Fine particulate matter formation, Ozone formation, Terrestrial ecosystems, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Human carcinogenic toxicity, Human non-carcinogenic toxicity, Land use, Mineral resource scarcity, Fossil resource scarcity, Water consumption)	Service Life Planning (ISO 15686)	
	ISO 14000 series, in particular ISO 14040 (ISO 14040 2006)	
	ISO 20887 "Design for disassembly and adaptability of buildings"	
	ReCiPe 2016 Midpoint/Endpoint	
	Environmental impact (Global warming, Ozone depletion, Photochemical ozone formation, Acidification, Eutrophication, Mineral and fossil resource depletion, Non-fossil resource depletion)	
	EN 15804 methods (EPD)	
	Environmental impact / Impact / kg x eq, Impact / MJ (Global warming, Ozone depletion, Photochemical ozone formation, Acidification, Eutrophication, Mineral and fossil resource depletion, Non-fossil resource depletion)	
	Circular Economy Life-Cycle Assessment (CE-LCA)	
	Environmental impact	
	Life cycle assessment (LCA)	
Environmental impact / Impact / kg x eq, Impact / MJ (Global warming, Ozone depletion, Photochemical ozone formation, Acidification, Eutrophication, Mineral and fossil resource depletion, Non-fossil resource depletion)	Multi-cycle Life Cycle Assessment (LCA)	
Toxicological footprint (Embodied and embedded human toxicity impact (Carcinogenic and Non-carcinogenic))	Life Cycle Assessment (LCA)	
Environmental impact / Impact / kg x eq, Impact / MJ (Global warming, Ozone depletion, Photochemical ozone formation, Acidification, Eutrophication, Mineral and fossil resource depletion, Non-fossil resource depletion)	Life Cycle Assessment (LCA)	
GHG Emissions	Life Cycle Assessment (LCA)	
Impact / kg	Material Flow Analysis (MFA)	
Economical	Total cost (€) and time in years	Circular Economy Life-Cycle Costing (CE-LCC)
	Economical impacts (Not defined further in the material)	Techniques of Life Cycle Costing (LCC)
	Positive effects (benefit) with the negative effects (costs)	Cost benefit analysis (CBA)
	Economical impact	Life cycle costing (LCC)
Parallel	Interaction between Lean principles and BIM functionalities	Building Information Model (BIM) + Lean Principles
	Standardization: Basic, Bronze, Silver, Gold, Platinum levels (5 assessment categories: Material Health, Material Reutilization, Renewable Energy, Water Stewardship and Social Fairness)	Cradle to Cradle Certified™ (version 3.1) (C2C Certified)
	Circularity potential (kg) (Product, Extraction, Social fairness, Toxicity, Reutilization)	Pre-Returnable Procurement® tool (version 3.1) (PRP)
	Standardization: Silver, Gold, Platinum levels (assessment categories: Air, Water, Nourishment, Light, Movement, Thermal Comfort, Sound, Materials, Mind and Community)	WELL Building Standard™ (version 2)
	RPR-rate (%) / Circularity potential (categories: Product, Extraction, Social fairness, Toxicity and Reutilization)	Relative product-inherent recyclability assessment (RPR)
	Score 1-5	Circular Built tool
	Building circularity ((Environmental impact (Enb), Economic impact (Ecb), Technical circularity rate (CRcb))	Building circularity calculation method (BCCM)
Environmental impacts of building materials (Global warming potential (kg CO <sub>2</sub> -eq), Cumulative energy demand (MJ), Ecological scarcity (Ecopoints)) and Indicators for regional economic benefits (Leontief multipliers calculated based on IOTs)	Integrated Assessment Model (IAM) (Material Flow Analysis (MFA), Life Cycle Assessment (LCA), Input-Output Analysis (IOA))	
Not defined	Not defined in the material	Flow analysis (MFA)
		Energy assessment
		Foot-prints
		Input-output analysis (IOA)
		Network analysis
		Life Cycle Assessment (LCA)

13 papers out of 18 (72.2%) operated only on one level out of four-level-categorisation, and these papers operated only on scales from micro to macro. 5 papers (27.7%) studied more than 1 scale or a combination of scales. All papers that operated on the systemic level (n = 4) were combined with another level and of those 3 papers out of 4 were with a combination of systemic and micro level. It seems from the examined materials that assessing buildings is seen as a vital aspect in assessing circularity in the built environment, but it is hard to define the boundaries in that aspect. For example, Life cycle assessment can be done for a building but even then, it will ultimately be done through components and materials according to the papers in this review. LCA with a circular and/or multi-cycle approach will make the process more complex and theoretical.

The third research question asked, 'Which life cycle stages are considered in circularity assessment?'. The life cycle approach to circularity has a strong connection to EN 15978 and EN 15804 standards and they were used as a basis for this question. Table 10 presents the data found from the research material and underlines that many of the papers did not meet the hypothesis in the set research question. Many papers did not present how they considered life cycles in their research. Especially those papers that based their methodology on LCA or used LCA as an assessment methodology, must have done life cycle analysis in light of the method, but did not present it in their articles. If the paper did not present or explicitly describe life cycle stages, the stages are not presented either in Table 10.

Only five papers out of 18 presented how life cycle stages were involved in the study. Out of the five, only three presented explicitly how they applied the EN-based stages in their research. Out of those three, two papers (Kayaçetin et al., 2023; Paiva et al., 2022) used the stages in a conventional way, considering a life cycle involving stages from A1 to D and that as the whole life cycle of the study scope item. Only one paper (De Wolf et al., 2020) presented a clear presentation of a multi-cycle life cycle approach (first cycle: A1-D, intermediate cycles (n-2): D-D, last cycle (n): D-D). On contrary to Sassanelli et al. (2019) work, only three papers (De Wolf et al., 2020; Eberhardt et al., 2020; van Stijn et al., 2022) presented an unambiguously multi-cycle approach in their papers. The multi-cycle angle involves theoretical parts that are affected by the number of cycles included and impact allocation approach used. However, multi-cycle perspective is a significant approach because it clearly separates the circular economy perspective from the sustainable one. van Stijn et al. (2022) presented a flowchart according to materials in different study scopes (kitchen variants and façade variants) and estimated possible number of use cycles and a theoretical approach to impact allocation with variables 'cycle-n' and 'cycle+n'. Eberhardt et al. (2020) present a flowchart with three cycles according to study scopes (building components).



## 5.4 Key findings and discussion

One of the most important finds of this work is that many papers studied circular solutions with methods and methodologies that are invented or created for assessing sustainability or measuring indicators that are created for sustainability impact assessment. In many papers (Wouterszoon Jansen et al. 2020; Stijn et al. 2021; Kayaçetin et al. 2023; Meglin et al. 2022) that were studied in this review, the known methods or methodologies for sustainability have then been further developed to meet the criteria for circularity assessment. This is a crucial observation because even if sustainable and circular built environment goals overlap greatly, it could be argued that there are also different interests in circular and sustainable assessment. It can be stated that if level of circularity on a product (e.g., building or building part) is assessed with only e.g., environmental impact, the aspect of circular economy remains quite limited.

Within this issue is also how requirements for measurability are formed and what is measured. Majority of the methods that emerged in this review were LCA or LCA based methods and the most used impact category was environmental impact and within that GHG emissions as shown in Tables 9 and 10. Sassanelli et al. (2019) found similar results “that many CE studies strive to include several life cycle stages in the analysis and that most methods are only focusing on the environmental aspect of sustainability”. Like in this review, in theirs, the result was explained by circular economy conceptualization and nature of LCA and MFA which were found to be the most often used methods for circular economy assessment (Sassanelli et al., 2019). Walzberg et al. (2020) agree that existing methods, such as LCA, MFA, Agent based modelling (ABM), System dynamics (SD), Environmentally extended input-output analysis (EEIOA,) have been developed for sustainable production assessment, and can be used to assess sustainability performance in circular economy context. Yet these methods cannot answer holistically to circular economy questions (e.g., the complex, dynamic, social, environmental, multi-actor, and multi-sector components of the CE) (Sassanelli et al., 2019; Walzberg et al., 2020). According to Kusumo et al. (2022) there is lack of uniformity of definitions and measurement standards within circular economy standards.

It seems that circularity impacts and indicators in built environment should be more researched, and it would be advisable to better clarify the differences between circular and sustainable indicators and assessment methods on top of those. Many papers concluded that methods overlap (De Wolf et al., 2020; Egemose et al., 2022). Yet also methods were criticized for narrow perspective of only a specific cycle (Zhang et al., 2021). Even if environmental impacts would be included in circularity assessment, they alone are not sufficient for that usage. Andersen et al., (2022) came to a similar conclusion in their review and concluded well: “... the agenda around CE should be acknowledged for being a means for mitigating other challenges [than climate change] as well” (Andersen et al., 2022). Standardization and clarification of qualities that reflect circular economy in built environment would help in this matter. With more target-oriented e.g., EU and national level-based regulations there will be a need for harmonized circular assessment to meet the set requirements in an equal way. De Wolf et al. (2020, 2) describes accurately:

“Consequently, results of these various approaches cannot be compared, combined, and predicted reliably. Worse, assessments can easily be tailored to produce desired results.”

Another important find is how largely LCA has its basis in circularity assessment and how a significant number of listed assessment methods in this review were methodologically based on LCA or were LCAs. Lindgreen et al. (2020) and (Andersen et al., 2022) and found similar results in their research. This aspect is essentially connected with the first find. Ultimately, conventional LCA was developed for a linear economy life cycle assessment (Curran, 2006). From this viewpoint, LCA has gotten critique for finding more sustainable solutions from and for the current linear system boundary. According to papers in this review (Eberhart et al., 2020; Paiva et al., 2022; Stijn et al., 2021; Santos et al., 2022) the reason why LCA is widely used in circularity assessment in general and also in built environment is in the strong background of standardization in LCA. The framework and process are well established and even made into businesses. It is seen a reason for its widespread usage when assessing environmental impacts and effects especially on environment and economy. From that basis it can be seen as a tempting opportunity to modify the tool to answer circular assessment.

Many papers in this review recognized the importance to address social aspects in the assessment but did not include that in their studies. This is partly reflected in Table 10 ‘Impact categories, indicators, and methods’, which presents which impact categories were regarded according to each method. Circular economy approach from ecological and economic viewpoint was seen as a priority to social aspects, and for that reason social aspects were left out in many papers. Also, social aspects are often seen as more difficult to define quantitatively. Most papers addressed that the aspects should be added to the equation in later phases. This can be seen as a knowledge gap and a strong recommendation on investigating social-related aspects in circularity assessment can be given. This view is supported by Ossio et al. (2023). The more holistic assessment method, the more comprehensive it is as well (Fet & Knudson, 2021; Sparrevik et al., 2021). Simultaneously, more holistic approaches induce more qualitatively measurable points, which makes the assessment demanding.

## 5.5 Limitations

The focus of this work was on the assessment viewpoint. This becomes partially visible in the search phrases and selected terms in search concepts (see section 4.1.1). A more in-depth study of the terminology and a precise definition of the terms could have opened new or limited more precise definitions in the used terminology. A lot of importance was put on the terms ‘circular economy’ and ‘circularity’. Studies that might have addressed circularity through R-strategy (reuse, etc.) might have been overlooked. This is a limitation that may have affected the material search, and some essential material may have been obscured when the material search was performed. Previous reasoning might have affected in a way that the Andersen et al. (2022)

publication did not come up in Scopus when their topic was in line with the motivation of this work and was published on that database.

There are limitations regarding the third research question which was possibly too specific to be answered in a scoping review, where the objective is to map out information instead of finding a specific answer to a specific question. More similar study models or methodological approaches from the search papers would have been more ideal and provided more fitting data for the third research question. Papers would have needed to include a case study, and the scale would have needed to be something else than systemic, possibly only micro or meso level scaling items. Some papers didn't declare or show life cycle stages because of the study design, e.g., if the paper was mapping or reviewing assessment methods. Some papers used data from other publication(s) and referred to them, in which case the data was not available in that publication. In some papers, the question setting was not ideal, e.g., if the research focus was on a systemic level or outside the research framing. It can still be seen vital that this question was asked, even if it was not sufficiently answered, because the results demonstrate how scattered the life cycle perspective can be. (De Wolf et al., 2020) demonstrate impressively in their research what kind of options theoretical calculations can create when considering calculation methods for impact distribution for future cycles. Studying emission allocation between multiple cycles brings a new perspective to circular economy research that also distinguishes it from conventional sustainability research.

It could be agreed that the setting for this work was also a limitation. The lack of no previous experience with the topic or scientific writing has undoubtedly affected the whole process. The process of the work was iterative, i.e., doing the research and learning about the subject at hand happened at the same time, and the process has influenced the progress of the work. While the work has been written, the number of papers found with the same search terms has increased. This tells about the topicality of the theme. Emerged papers could have been added to the pool of papers used in this work, but this was not done because this was not a paid work and due to the already limited time the writer had available. Some decisions made at earlier stages might have been done differently, but this could also be described as a process of learning.

Some limitations are since only one database (Scopus) was used. Only English was used as a search language, i.e., publications in other languages may have been overlooked. One limitation comes from the set exclusion criteria, which refer to only peer-reviewed articles. Available knowledge from non-academic fields, e.g., professional publications or organizations' guidebooks, was not included, and some available knowledge from such references might have been overlooked.

## 6. CONCLUSIONS AND REFLECTION

In this thesis methods to assess circularity in the built environment on four different levels were studied and inventoried using a scoping review. In the literature search, a total of 52 papers were identified, and finally 18 papers were found eligible for the research. The main objective of this study was to find out what kind of methods exist to assess circularity in the built environment. A framework of four different levels was recognized (systemic (policies and regulations), macro (city and regional level), meso (buildings), and micro (building parts, components, and materials)). Within the scope of the main objective, a look to metrics related to the assessment methods was also done. What was also studied was which life cycle stages were considered in circularity assessment. As a result, circular economy approaches were studied with broad sampling and methods were found to be applied on all levels in the review framework. The results show that the built environment levels interconnect but, according to the key findings, when operating only on one level the micro level works best on its own. Environmental impact was found to be the most used impact assessment category. Only a few papers studied multi-cycle approaches on a life cycle basis, and in those studies impact allocation was the object of study. This work broadly shares results with similar reviews to this one done by Andersen et al. (2022) and Lovrenčić Butković et al. (2021) but highlights the connection between different assessment methods and different levels of built environment.

This work starts with the premise of the global resource and energy consumption and how the circular economy and sustainability can address them. Circular economy is not free from critique as a concept. For example, a circular economy can be seen as a geopolitical insurance where the economic growth of the Global South threatens the stability of the Global North, having and using resources as they please (Pomponi & Moncaster, 2017). This addresses the behavioral change that is needed in consumption patterns, especially in the Global North. Simultaneously, the sustainable development paradigm has been popularized and translated into business strategies. It has been questioned whether the circular economy is a new paradigm of our time, which, behind the beautiful words and goals, makes it again possible to run the economy in a business-as-usual way. 'Sustainability' or 'circular economy' are also marketing strategies, and circular economy with novelty value compared to sustainability can sound more interesting to the consumer than sustainable development. This work contributes to a wider scientific picture, in which research with transparent methods aims to solve not only resource and energy consumption, but also to reduce the possibility of greenwashing and misuse of these goals. The importance of interdisciplinary research in behavioral change can be highlighted.

It is essential to note that the circular economy takes place on many levels at the same time, and not necessarily always with the same operating principles or even goals. In the pursuit of a circular economy, different implementation goals are set for change measures. LCA, EPD and many other

lower-level (less traversed) methods closely follow the current system boundary but enable circular economy and product development even on a fast schedule. At the same time, the aim of sustainability is to make a systemic change from a linear economy to a circular one. Such change takes place at a higher-level, i.e., more holistically and comprehensively (more traverse). A more holistic and comprehensive process is dependent on behavioral and societal change and therefore takes time. It can be considered beneficial that development takes place on many levels at the same time, because changes at different levels then can respond to short- and long-term change needs.

This work demonstrates that circular solutions are assessed with methods and methodologies that are invented or created for assessing sustainability or measuring indicators that are created for sustainability impact assessment. If only one indicator is used in assessment, e.g., environmental impact, it can be questioned whether it evaluates the circularity of the chosen scope well enough. There is a lack of unity in the circular economy description and indicators, which can produce confusion with method selection and usage. Life cycle assessment was the most used method or methodology, and completely novel methodologies were only a few.

This work illustrates that measures at different levels of the built environment can conflict, and therefore it is not always reasonable to make a comparison between actions on different levels. Even at the same level contradictions may occur depending on which goal is being targeted. This is the case e.g., in the review by Santos et al. (2022), where they compared the environmental performance of a business-as-usual composite made from raw material and a composite developed from a by-product. The former had a clearly better environmental performance, but they argued that at the end-of-life phase, the latter had value in biodegradability. Also, in that case, the use of by-products implemented the R-strategy, i.e., reduced use of virgin material, but in LCA comparison, it produced higher GHG emissions.

It is important to remember that increasing circularity will not automatically lead to a more sustainable environment, e.g., by reducing environmental impacts. (Ossio et al., 2023; Antwi-Afari et al., 2021; Zink and Geyer, 2017) This aspect was also witnessed in Santos et al. (2022) work with reinforced sisal fibers. How methods are applied, who applies them and in what context are still valuable aspects to consider. Raising awareness and skills is an integral part in the system change from linear to circular model. Recommendations for working with these themes in education can be given, especially with design principles and reused or reclaimed material.

As a scoping review, the starting point for this work was to scan what kinds of assessment methods can be found in the built environment. Based on the initial research, what was expected to be found were LCAs and other existing methodologies, and this expectation was met. On top of the found methods what would have been interesting to find out relates to qualitative assessment, e.g., qualitative aspects of the usage rates or adaptability of spaces or premises and how these relate to circularity. Another aspect that was not fully met in the researched material were the aspects of building maintenance or demolition and assessment related to them. From a resource perspective, demolition produces waste and can enable new construction on site, which

is often followed by a carbon spike. Dismounting of building parts is part of the aspect where buildings are seen as material banks. This was researched by Marzouk et al. (2019) with the aspect of combining Building information modeling and finding dismantlable building parts. Assessment of qualitative attributes in building construction would enable a long life span for a building and would reduce demolition and negative effects related to that.

There is a lack of unity in the circular economy description and indicators, which can create confusion with method selection and usage. In order to be able to understand how circularity can be assessed, it is vital to understand how sustainability and circularity overlap, how both are assessed and to understand the differences between approaches. This applies to circularity and sustainability discourse in general, where the built environment is no exception. Further research on this topic can be highly recommended. To support the transition from a linear to a circular economy, the built environment would benefit from more uniform definitions and standardization. Method development can continue separately on different levels, but attention should be drawn especially to the context in which they are being applied and transparently disclosed. There is a need for an industry specific framework that would develop the industry holistically towards circular practice. Further research should focus on a more comprehensive assessment of circularity and include qualitative measures, including social-related aspects.

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