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Circular Economy Principles and Planetary Boundaries

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1 ABSTRACT

Urban development requires a distinct understanding of the existing situations as well as a vision of the future district to be able to develop suitable pathways for a sustainable transition. The debate conducted so far highlights the need for a comprehensive understanding of the different aspects of circular economy (CE) principles impacting the sustainability, in particular what needs to be done with regard to environmental sustainability in cities and regions. To be able to build a representative methodology for integrated sustainability assessments the concept of Planetary Boundaries (PB) was selected as a framework to analyze how to establish a holistic sustainability evaluation based on CE. Previous work showed that although some principles have already been identified and implemented, several relevant trigger points of PB have not been considered yet. By combining CE methods, urban planners and policymakers can gain a holistic understanding of the impacts of urban districts on planetary boundaries. This knowledge can inform sustainable urban development strategies that minimize environmental harm, promote resource efficiency, and enhance the well-being of urban communities.

Keywords: economy, urban development., planning, sustainability, environment

2 INTRODUCTION

Various environmental problems such as biodiversity loss, water, air and soil pollution, resource depletion and excessive land use are increasingly threatening the Earth's life support systems. Especially in today's linear economic models with the "take, make, dispose of" concept raw materials are extracted, processed, used and then disposed of as waste (economiesuisse 2023). This approach leads to a high consumption of limited natural resources (Geissdoerfer et al. 2017).

Traditionally, the construction industry has also historically pursued an unsustainable, linear economic model based on the "take, make, dispose of" concept and seems to continue to do so (compare e.g. EMF, 2015). This linear approach does not allow for the targeted dismantling of buildings and the reuse of materials, components, or elements to conserve resources and reduce the need for new raw materials (Ghufran et al. 2022). The built environment plays a significant role in terms of resource consumption due to its significant environmental impact, but at the same time it also offers great opportunities to reduce energy consumption, greenhouse gas emissions and waste emissions (Pomponi and Moncaster, 2017).

A look at the annual status reports of the United Nations Organizations (UN), the International Energy Agency (IEA) and the Global Alliance for Buildings and Construction (GABC) shows the importance of the construction and real estate industry in the global context of energy consumption – the industries in question are responsible for 36% of global energy consumption and 39% of CO_2 emissions (Röck et al., 2020). The figures from 2015 underline the importance of construction in energy and material consumption, also in Switzerland, where, for example, 40% of energy and 50% of material inputs were consumed, while at the same time 75% of waste was generated by this sector.

It is becoming clear that there is an urgent need for a transformation of the construction and real estate industry towards a circular approach. This is where the circular economy strives for better management of resources.

3 BACKGROUND

A recent study provided a practical application of CE in urban regeneration. It combined CE principles with urban redevelopment and showcased how traditional "brownfield" sites can be transformed into sustainable, vibrant communities. This approach represented an attempt to shift from the linear economic model, offering a replicable model for sustainable urban development driven by Nature-based solutions.

The integration of a CE models demonstrated that a conscious use of resources and a clear positioning against the linear economy is needed. The proposed method and tools not only offered efficient planning options, but also emphasised the emotional value of sustainability for the identity and history of the environment. Nevertheless, although the findings underline the effectiveness of this CERE model of energy generation and utilisation in the context of sustainability and the circular economy principles, it became clear that the implementation of a CE concepts often goes beyond technological progress by creating efficient, sustainable urban sites, there are certain shortcomings:

- The study contributed to the field by providing a practical application of CE in urban regeneration.
- It innovatively combined CE principles with urban redevelopment, showcasing how traditional "brownfield" sites can be transformed into sustainable, vibrant communities. It did not quantify the environmental benfits not the consequences in quantitative way.
- The approach represented a significant shift from the linear economic model, offering a replicable model for sustainable urban development driven by Nature-based solutions. However, it is not clear if these developments will help to stay within our planetary boundaries.
- In the realm of urban redevelopment there are approaches that redefine the transformation of traditional brownfield sites. Some extend beyond conventional approaches, exploring novel possibilities for real estate products. However, a clear link between urban development and planetary boundaries is still missing.

3.1 Circular Economy

Desing et al. (2020) highlight the lack of consensus and a uniform definition for "circular economy", despite its widespread use (also see Kirchherr et al., 2017). According to them, the Ellen Mac Arthur Foundation (EMF 2015) definition, which emphasizes the regenerative economy and new business models, is the most cited and recognized. This definition has been widely adopted or modified by policymakers and institutions like the European Commission.

The Laboratory for Applied Circular Economy (LACE) proposes a resource-based definition of the circular economy, aimed at human well-being, but acknowledging biophysical and planetary boundaries. These limits are considered absolute and quantifiable for the resource base used for human activities (LACE). Definition of the circular economy is:

The circular economy is a model that adopts a resource-based and systemic view and aims to take into account all the variables of the Earth system in order to maintain its viability for people.

In a recent study by Haase et al. (2024), a collection of CE models is presented that helps to complete our understanding of the opportunities and limitations of CEM. Important key strategies for the application of the circular economy over the entire life cycle of a building circular economy strategies in general were collected and its applicability for the built environment was reviewed.

One finding was that "The multitude of definitions of CE, and more specifically circularity in the built environment, does not contribute to a coherent, systematic approach. CE needs to be viewed as a business strategy, not only waste management or a design strategy. Optimising buildings' use should also be spotlighted instead of only viewing those as potential material banks where components and materials can be recovered, reused, or recycled for new constructions …. Still, recovered materials from existing buildings face a critical barrier in their technical compatibility and quality appraisal, which put their direct reuse in question, leading to downcycling processes and engaging extra resources and energy flows."

It further concluded that "The circular economy is seen as a regenerative system in which resource use and waste as well as emissions and energy losses are minimized, waste is avoided and material and energy cycles are slowed down, closed, and narrowed. This can generally be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, or recycling. In the context of the real estate and construction sector mentioned, this means that no new resources are required in the production of materials and waste is also minimized. In addition, better resource management is sought by reducing consumption (or even avoiding unnecessary consumption) and striving for resource circulation through the reuse or recovery of materials and components." (Haase et al. 2024)

The strategies could be assigned to the individual life cycle stages of a building, and differentiated between the design, construction, and end-of-life phases. Some key strategies are explicitly focusing on specific life cycle stages, such as Material Banks, Design for Adaptability, etc. On the other hand, most strategies include some sort of information and data management, like Adoption of Efficient Processes, Waste as a Resource, and Resources Data Management. By comparing the different origins, it explains the opportunities and limitations of the different models. Thus, it provided one important knowledge gap of our current understanding of CE. However, there seem to be more knowledge gaps that need to be filled.

3.2 Earth system boundaries

The concept of planetary boundaries describes limits to the impacts of human activities on the Earth system. These boundaries represent thresholds beyond which the environment may not be able to self-regulate anymore. It was proposed, in 2009, by Rockström and Steffen (Rockström et al. 2009; Stefffen et al. 2015). The concept introduced the much-discussed idea that, if we exceed these limits, we risk destabilizing the Earth system and moving away from the period of stability known as the Holocene, during which human society developed. The framework is based on scientific evidence that, since the Industrial Revolution, human actions have become the main driver of global environmental change.

In the PB concept, the thresholds, or tipping points represent the value at which a very small increase of the control variable (e.g., CO2) triggers a larger, possibly catastrophic change in the response variable (e.g., global warming) through feedback in the natural earth system. The threshold points are difficult to locate because the earth system is very complex. Instead of defining the threshold value, a range was established, where the threshold is supposed to lie inside it. The lower end of that range is defined as the boundary. Therefore, it defines a 'safe operating space', in the sense that as long as we (as mankind) are below the boundary, we are below the threshold value. If the boundary is crossed, we enter a danger zone (Steffen et al. 2015)

A recent study by Richardson et al., suggests (2023) that six of the nine boundaries are transgressed, which means that “the Earth is now well outside of the safe operating space for humanity” (Richardson et al. 2023).

The focus in future research is on quantifying the control variable PB of ‘green water’ and understanding the risks and dynamics through which ‘green water’ perturbations can disrupt Earth system resilience.

It should aslo be noted that on the other hand there are some PB not yet quantified. So some efforts are put on defining those PB. E.g. Novel entities refer to substances, materials, and organisms that are introduced into the environment as a result of human activities. These can include i) chemicals and plastics; ii) new materials ii) genetically modified organisms (GMOs). The concept of a planetary boundary for novel entities is still under development, however, some scientists believe it has already been transgressed due to the widespread presence of plastics and chemicals in the environment. Wang et al. (2022) collected or more details on each PB shown in Figure 1.

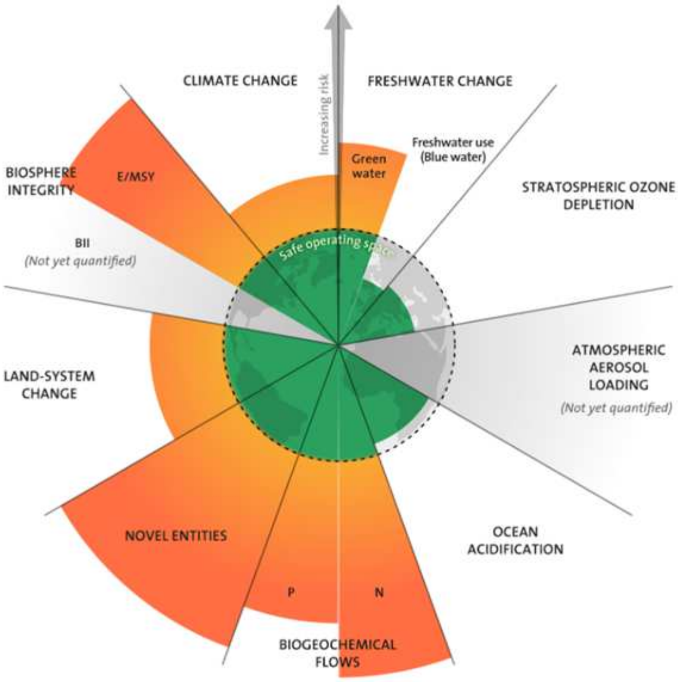

Figure 1: Estimation of planetary boundaries change from 1950 to 2022 (Wang et al. 2022)

4 METHOD

The approach involves:

- Dicussion of CE principles for the Real Estate and urban development
- Collection of tools and methods that are needed
- Analysis of value creation and its relation to planetary boundaries

5 INTRODUCTION OF THE CERE MODEL

Based on the case study a method was developed and is presented that is based on four pillars:

(1) Determination of CE concept and alocation in the Circular Economy in Real Estate (CERE) model

(2) Choice of a method and a tool for the chosen CERE model

(3) Determination of data needed to measure the circularity, including stakeholders identification

(4) Specification of business model by using Sustainable Business Model Innovation (SBMI) to specify all input needed.

Fig. 2: CERE model for urban sites

5.1 CE concepts

Based on an analysis of existing CE models, a new model tailored to the real estate lifecycle management was proposed (Haase et al. 2024) Here, the principle should be allocated as described in Table 2.

CE Principle	Description and planetary boundary impact
Ressource Efficiency	Reducing the demand for raw materials impacts the Earths biochemical flows. Reducing energy consumption impacts the climate change. Minimising land and resource use impacts the change in the land-system
Regeneration	Implementing regenerative practices, such as green roofs or parks influences the biodiversity loss boundary by creating habitats and supporting ecosystem services.
Reduce	Restricting resource flows throughout the life cycle of buildings (Share, Reuse, Repair) affects several boundaries, including climate change (reduced greenhouse gas emissions), freshwater use (lower consumption), and land-system change (less resource extraction).
Decelerate / Slow	Slowing down resource flows by intensifying use and extending useful life influences the planetary boundaries related to waste production and resource depletion.
Closing	Returning resources to the cycle at the end of their life affects mainly the chemical pollution boundary.
Cooperation	Fostering collaboration between supply chain actors facilitates a holistic management of all boundaries by promoting integrated solutions.
Digitalization	Efficient handling and systematic collection of information and data over the entire life cycle of a building to increase transparency, traceability and optimization of processes would impact all boundaries.

Table 2: Basis of CE principles in CERE model (Haase et al. 2024) and their impact on planetary boundaries

By incorporating these principles, the real estate sector can play a crucial role in maintaining the Earth's systems within safe operating spaces, addressing multiple planetary boundaries, and contributing to a sustainable future.

5.2 Methods and tools measuring circularity and the contribution to Panetary Boundaries

In practice, the circular economy encompasses a broad range of industries, from manufacturing and construction to fashion and electronics. It involves adopting innovative technologies, material recycling, reverse logistics, and sustainable procurement practices to close the loop on product lifecycles. This step involves choosing a method and a tool from real estate lifecycle which you would apply for your case. This step should be supported by giving the reasons for the choice and specification of the information need to use the tool amd method. There are emerging tools and methods that can be explored. They differ in how to quantity the circularity of a proposed measure.

Beyond waste reduction, the circular economy seeks to regenerate natural systems. This includes promoting regenerative agriculture, reforestation, and sustainable land use practices to restore ecosystems and biodiversity. The urban developer should explain how he/she would measure the circularity of his/her project. It starts with listing the data needed to measure the circularity, which stakeholders are needed to involve, and which values are created in the project.

Ultimately, the tool should relate to the planetary boundaries. What trigger points are moved in which direction and by how much? Is it beneficial to do the urban development or does it increase the trigger points?

Table 3 shows emerging tools that are currently under development. They focus on different levels (Building, Component, Material) and in different phases. An important distinction is the post-use phase and the pre-use phase. While pre-use phase focuses on the period before the start of the use phase. Finally, a dinstinction can be made regarding the sub-indicators.

method / scope		Circularity score (SC)	Concular Circularity Performance Index (CPX)	DGNB Circularity Indesx (DGNB CI)	EPEA Circularity Passport Buildings (CP)	IBO Disposal Indicator (EI)	Madaster Circularity Indicator (MCI)	Urban Mining Index (UMI)	Recycling Graph	Circularity Index BSRRI
level		B C M	B C M	B C M	B C M	M	B M	B C M	C M	B C M
phase		post-use	pre-use, post-use	pre-use, post-use	pre-use, post-use	post-use	pre-use, post-use	pre-use, post-use	post-use	post-use
sub-indicator	pre-use		material origin construction waste, pollution	material origin, construction waste, pollution	material origin, CO2 pollution		material origin, CO2 pollution	material origin, CO2 pollution, pollution		
sub-indicator	post-use	R DA MR	R DA SRM MR	MC R DA SRM MR	DA SRM MR	MR	DA MR	MC R DA SRM MR	DA MR	MC R MR

Table 3: Emerging tools for circularity. B: Building level; C: Component level; M: Material level, MC: Material compatibility; R: Reusability, DA: dismantling ability, MR: material recycling; SRM: separability of recyclable materials

Circularity score (SC)

This method was developed at RWTH Aachen in Germany with the goal to establish a widely applicable and easy-to-determine indicator of the expected circularity of buildings. So far, only a few approaches exist in the academic environment of a few colleges and universities. A higher level of applicability of the Circularity Score is envisioned in an early planning phase, e.g. the HOAI - Phase 2 (pre-planning). This ex-ante approach makes it necessary to examine and evaluate numerous fundamentally possible and probable combinations of building materials in a building with a view to their later separation and reusability. The BBSR's eco-building data, which is frequently used in the construction industry for life cycle assessment issues, knows over 1,000 building materials and components from which possible and probable building material combinations are determined. These are then aggregated in the context of the building to form a total number named the Circularity Score.

Concular Circularity Performance Index (CPX)

The Concular Circularity Performance Index (CPX) is a tool developed by Concular specifically for assessing the circularity of buildings and construction projects. CPX is specifically tailored to the construction sector, considering aspects relevant to building materials, design, and end-of-life options.

Quantitative Assessment: It assigns a score (likely ranging from 0 to 100) to a building project, providing a quantifiable measure of its circularity performance. It leverages Concular's own database of materials, pre-populated with circularity factors for various building components. This can streamline the assessment process. The initial score can be adjusted by planners or building owners to reflect project-specific details and decisions. Public information about the specific methodology behind the CPX is scarce. Transparency regarding how the score is calculated is crucial for users to understand its strengths and limitations. Thus, the accuracy of the CPX assessment relies heavily on the comprehensiveness and quality of data in Concular's internal database. Since Concular offers other circularity-related services, there might be a concern about potential bias towards their solutions when using the CPX.

DGNB Circularity Indesx (DGNB CI)

The Circularity Index of DGNB (DGNB CI) is a tool developed by the German Sustainable Building Council (DGNB) to assess the circularity performance of buildings. DGNB is a well-recognized organization in sustainable building practices, lending credibility to the DGNB CI. The index considers the building's entire life cycle, from material extraction and construction to use and end-of-life management. This aligns well with circular economy principles. DGNB CI goes beyond just material circularity. It incorporates aspects like design for disassembly, potential for reuse and recyclability, and waste management practices during construction and demolition. The methodology behind the DGNB CI is publicly available, allowing users to understand how the score is calculated and interpret the results effectively. The DGNB CI can be complex to use, especially for projects without prior experience with DGNB's sustainability rating system. Conducting a comprehensive assessment using DGNB CI requires detailed information about building materials, their origins, and potential for reuse or recycling. Gathering this data can be time-consuming and resource intensive. While the core principles of DGNB CI are applicable globally, some aspects might have a regional focus, potentially requiring adjustments for application in different geographical contexts.

EPEA Circularity Passport Buildings (CP)

The EPEA Circularity Passport Buildings (CP) is a tool developed by EPEA, a consultancy specializing in cradle-to-cradle design principles. It focuses on creating a digital record of a building's materials and their circularity potential. The EPEA CP promotes transparency by creating a digital passport that tracks the materials used in a building. This facilitates future reuse, recycling, and overall material management. EPEA's cradle-to-cradle approach emphasizes using healthy and environmentally safe materials in construction. The CP reflects this focus, potentially leading to buildings with a positive impact on human and environmental health. The EPEA CP can be integrated with design and construction workflows, promoting circular considerations from the outset of a project. The digital passport concept could be used in future applications like facilitating material exchanges or connecting buildings with dismantling and recycling facilities. The EPEA CP primarily focuses on material documentation. It doesn't provide a comprehensive circularity score or assessment of other aspects like design for disassembly or operational efficiency. The accuracy of the information in the CP relies on the quality of data entered by designers and builders. Integrating the CP effectively within existing design and construction workflows might require additional training or adjustments for project teams.

IBO Disposal Indicator (EI)

The disposal indicator was prepared by the Austrian Institute for Healthy and Ecological Building (IBO) for the uniform assessment of the disposal properties of construction and materials at building level. In the semi-quantitative method, the current disposal route of a component or the recycling potential that would be possible from an economic and technical point of view if the framework conditions were improved up to the assumed point in time of disposal of the construction product are evaluated on a scale of 1 to 5. The higher the expenditure for dismantling and recycling and the more negative the effects of disposal are on the environment, the worse the classification at building material level. The disposal indicator plays an important role in the climate-active building evaluation programmes Building and Renovation and Total Quality Building (TQB).

Madaster Circularity Indicator (MCI)

The Madaster Circularity Indicator (MCI) is a tool developed by Madaster, a platform focused on building transparency through material passports. It assesses the circularity performance of buildings throughout their life cycle. Madaster's MCI is directly linked to their material passport system. This creates a seamless connection between documented building materials and their circularity potential. The MCI considers all stages of a building's life cycle, from material extraction and construction to use and end-of-life management. Madaster emphasizes transparency by allowing building owners and stakeholders to access detailed information about the materials used in the building. The accuracy of the MCI score heavily relies on the completeness and quality of data recorded within the Madaster platform's material passports. The specific methodology behind the MCI calculation might not be entirely transparent to users outside of the Madaster platform. Madaster offers various circularity-related services. There might be a concern about potential bias towards their solutions when using the MCI.

Urban Mining Index (UMI)

The Urban Mining Index (UMI) is a tool developed to assess the potential for recovering and reusing materials from buildings at the end of their lifespan. It focuses on the concept of "urban mining," which refers to extracting valuable resources from existing structures rather than relying on virgin materials. The UMI specifically targets the potential for recovering and reusing building materials, aligning well with circular economy principles. While the primary focus is on the end-of-life stage, the UMI might consider aspects throughout a building's life cycle that could influence its disassembly and material recovery potential.

Quantitative Assessment: The UMI aims to provide a quantifiable score or indicator to assess the recoverability of a building's materials. Information about the UMI can be scarce. The specific methodology behind the UMI calculation and details on how the score is interpreted might not be readily available. Using the UMI effectively might require expertise in building materials, deconstruction practices, and market conditions for recycled materials. The UMI's development might have originated in a specific context. Its applicability in different regions could be affected by factors like local regulations and recycling infrastructure.

Recycling Graph

The RecyclingGraph approach was developed by Schwede (2019) can be used to translate detailed models of constructive designs into a numerical representation that can be processed by computational algorithms and design tools (SChwede 2019). This method can be utilized to evaluate designed and pre-designed structures and a catalogue of qualified design templates can be build up to support the BIM-based design development. The RecyclingGraph approach has potential to be further developed and implemented in applicable design tools. However, further aspects could also be integrated, e.g. on the ability of disassembly for common connection principles or on the compatibility of material combinations.

5.3 Value creation and planetary boundaries

The circular economy is gaining global momentum, as various organizations, governments, and businesses actively pursuing circularity to tackle urgent environmental challenges, lower carbon emissions, and foster economic resilience in an increasingly resource-constrained world. The final step involves specifying the project`s business model. To achieve this, the SBMI framework can be utilized, requiring specific inputs. These include defining the value creation process, identifying stakeholders and their roles in the project, and outlining the market opportunities for the business concept.

At the core of effective circular business innovation is design thinking, a methodology that emphasizes human needs, empathy, and collaboration (Lawson 1997).

Once a sustainable business innovation has been identified and a CE concept has emerged, it is crutial to include evaluation of the trigger points of our planetary boundaries.

- Global freshwater systems considerations should be centrally embedded in the local water cycle in urban planning and design processes, deploying Nature-based Solutions, and resource circularity.

Aiming at sustainable water management, rainwater collection, treatment, and reuse, as well as selecting building materials and products with low water inputs can further reduce impacts on freshwater resources. The goal must be to improve the availability of water sources while minimizing ecological impacts and reducing flood risk. A proactive management of natural water processes through Nature-based Solutions, from catchments to buildings and open spaces.

- Urban developmnets influence biodiversity and degradation of the quantity and quality of urban habitats. So, the focus should be on reducing the embodied ecological impacts in materials, food, and other products; and planning linear infrastructure to protect, restore, and connect habitats. A prioritization of resilient vegetation in urban green spaces can improve species intactness and biodiversity through appropriate habitat provision. Another focus should be put on the blue-green infrastructure which helps to improve aquatic biodiversity. This implies improved water quality through reduction and appropriate management of contaminated runoff; the enhancement of treated sewage discharge; the support of conscious water use; and the restoration of freshwater and coastal habitats.
- Urban infrastructure is a critical component in redirecting nutrient flows to balance areas of excess to areas of need and to close cycles. Sewage sludge, food, and yard waste can become resources rather than costs if appropriately managed in a circular metabolism approach. These nutrient inputs can be converted into biogas through anaerobic digestion, which produces a by-product called digestate. Digestate from food and yard waste can then be applied as a fertilizer and/or soil amendment to improving soil qualities and reducing the need for chemical fertilizer. In urban developments, opportunities to create local facilities to enable circular nutrient flows can be identified. Strategically placed green-blue infrastructure and Nature-based Solutions, such as raingardens, bioswales and wetlands, can reduce eutrophication by safely soaking up nutrients in runoff. Planned in a "good" way, urban sites can also reduce indirect nutrient pollution from agricultural imports through sustainable food sourcing and by scaling up local food production. Hydroponics and other sustainable production systems, when contained in controlled environments, tend to have high nutrient efficiency and little to no runoff.
- There is a possibility in urban developments to reduce aerosol pollution by mitigating the major sources of particulate emissions, including use of fossil fuel combustion for energy, transport, and industry, and minimizing construction and demolition dust. Clean or electrified heating and cooling, transport, cooking, and industry from renewable sources can reduce local emissions. Electricity generation must also be emissions free to avoid simply shifting the geography of aerosol loading.
- Clean and renewable energy generation (in addition to demand reduction) is fundamental to reducing net loading, yet intermediate actions can be taken during the infrastructure transformation to immediately reduce aerosol emissions such as retrofitting existing power plants with wet scrubbers that remove particulates at the source. In sectors that are challenging to electrify, hydrogen fuel can be used; the only aerosol emitted through its combustion is water, yet the hydrogen must be produced cleanly as well.
- Dust emissions can be reduced during construction and demolition through controlled deconstruction (which supports component reuse), the use of protective screening, and the application of water for damping down.
- Vegetating temporarily vacant lots can reduce dust emissions and mitigate the urban heat island effect while supporting local biodiversity.
- Novel entities cause a major concern, with widespread plastic pollution and the introduction of various synthetic chemicals into ecosystems. Also engineered nanomaterials and other advanced materials raise concerns about their potential long-term environmental impacts. The introduction of genetically modified organisms into the environment poses potential risks to biodiversity. The long-term effects of novel entities on ecosystems and human health are often not fully understood. Design of urban areas under CE principles should therefore avoid these novel entities despite their unpredictability.

6 DISCUSSION

From this research it becomes clear that there is an urgent need to link CE principles with planetary boundaries. Only if we manage to quantify the amount of moving trigger points with the help of CE principles it will allow us to quantify the real value of CE.

Planetray boundaries have the potential to add useful inventory of the current use of the circular economy concept in the built environment. It has not been incorporated yet because there are several issues

(1) The planetary boundaries have been found for our activities on the planet. It is yet to be downscaled to national, regional or even local dimensions. Attempts for this have been made (add ref.) but it remains unclear how effective this approach is.

(2) To upscale local activities towards PB is anotother promising approach (add ref.). However, this implies asessment and certification schemes that are already on the market (and have customers in the building industry) adopt these boundaries. The definitions and effects on the cicular economy are not yet established and there can be expected some resistance from major actors against the consequences from establishing PB in the construction industry.

(3) To date, there is no consensus on the planetary boundaries, how they are measured and assessed, and this issue would also need to be addressed (e.g. agreed targets of GHG emissions and lack of implementation) with focus on the building industry.

It will be important to explore further the relation between measures on the existing building stock and the materials, components, and buildings already in use and new constructions and their impact on the future life period of the urban site. In this sense, each urban development has two aspects to measure the circularity, a pre-use and post-use circularity. More work is needed to develop these methods further.

7 CONCLUSION

The study of the methods and tools currently under development shows that their focus is not on the planetary boundaries. Some tool was developed mainly with the aim to minimize impact compared with a "base case". Then certain measures can be used to offset impacts (e.g., the renewable electricity produced onsite can be used to offset GHG emissions from the grid). This concept is therefore heading only for a better than usual approach and does not appear congruent with the planetary boundaries approach, which is framing precise thresholds for development. On the other hand, the CE does not try to stay within the planetary boundaries. On the contrary, a CE use is allowed for every citizen, and even though this implies a very small footprint, it allows certain boundaries to be reached and crossed.

There are two key aspects that need to be integrated: First, starting with PB, there should be a regionlising of tipping points in regenerative sustainability models for the built environment. This would allow us to plan and design for urban and peri-urban ecosystems that stay within the planetary boundaries.

Secondly, regeneration of the full Earth system will require a fundamental shift in the way we think about our relationship with the planet. We have to re-think what a balanced human-planet relationship might look like and ultimately provoke passion to drive change for ourselves and the next generation. Urban developments can have a profound impact on the PB. By adopting sustainable and environmentally responsible urban development practices can help to protect the planet, enhance resilience to climate change, and create healthier, more equitable communities for future generations.

By combining CE methods, urban planners and policymakers can gain a holistic understanding of the impacts of urban districts on planetary boundaries. This knowledge needs to be developed further as it can inform sustainable urban development strategies that respect the Earth`s limits, while promoting economic growth, resilience, resource efficiency, and enhance the well-being of urban communities.

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