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THREE OBJECTIVES FOR A HOLISTIC CIRCULAR ECONOMY POTENTIAL ASSESSMENT OF BUILT ASSETS

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ABSTRACT

Background and aim. Built assets can contribute to the circular economy (CE) in several ways, implying there are multiple CE objectives to consider. Existing measurement methods often yield suboptimal results for objectives that are not their focus. We are developing a holistic method for measuring the CEP of built assets; the present paper proposes three key CE objectives essential for a holistic CEP calculation.

Methods and Data. A holistic set of CE objectives encompasses all relevant end-of-use and end-of-life strategies for the CEP of a built asset. We analyse existing circularity quantifications, identify challenges that prevent a holistic assessment, and determine the requirements for a novel set of CE objectives. Furthermore, we propose and verify the novel set of objectives using the CEP framework and three illustrative use cases.

Findings. The three objectives for a holistic CEP assessment are longevity, reusability, and transformability. Longevity implies that a resource remains in place; reusability refers to outflows that retain a similar form and embodied value; and transformability involves the outflows that change their form. Through validation we demonstrate that these objectives apply to previously identified CEP influencing factors and all use cases.

Theoretical / Practical / Societal implications. The novel system of objectives provides a foundation for more accurate measurement of the CEP in the building sector. The proposed set is sufficient for navigating the complex landscape of CE assessments, strategies and parameters. A quantification method encompassing all objectives and reliably reflecting real-world performance would incentivise more circular design of built assets.

KEYWORDS: adaptability, building configuration, circularity, flexibility, quantification.

1 INTRODUCTION

1.1 CIRCULAR ECONOMY IS A PARADIGM ENCOMPASSING A RICH SET OF PRACTICES

The growing environmental impact of the construction industry is increasingly recognized in both research and practice (Bertino et al., 2021). A potential solution to reduce this unsustainable influence lies in approaches encapsulated within the concept of the circular economy (CE). The principles of CE are diverse and encompass a broad set of recommendations: eliminating waste and pollution, circulating products and materials, and regenerating nature (Ellen MacArthur Foundation, 2021). However, only certain approaches are directly relevant to the construction industry. While it is widely accepted that transitioning to more sustainable practices is essential, and that the construction industry plays a pivotal role in this transition, it remains challenging to quantify and compare the effects of different practices. The construction industry faces specific challenges and requirements for achieving this transition, which have been the topic of multiple literature reviews. These reviews focus on multiple aspects, such as multiple phases of the building lifecycle (Cimen, 2021), strategies influencing CE practices (Eberhardt et al., 2022), obstacles to implementation (Charef et al., 2021), or company-specific implementation (Nunez-Cacho et al., 2018). Consolidating this extensive set of influencing factors into a measurable set of performance indicators has to our knowledge not been achieved.

1.2 MEASURING BUILDING CE POTENTIAL IS A CRITICAL OBSTACLE

The inherent CE potential (CEP) of built assets refers to the various ways in which built assets and their sub-parts can support or hinder CE, some of which are challenging to measure. We use the term "built asset" as defined in ISO 19650 (ISO, 2018), as it encompasses both infrastructural constructions and carries an economic meaning. However, terms like "construction asset", "built object" or "built structure" are also appropriate. Prior studies have identified two critical obstacles to effectively leveraging CE principles: a lack of a holistic perspective on CE performance (Ossio et al., 2023) and a lack of practical methods for its measurement (Eberhardt et al., 2022; Hossain et al., 2020). In our previous work, we explored multiple quantification methods for the CEP which consider the configuration of built assets and its relation to the CE (Sibenik et al., 2025). The ultimate goal of our research is to develop a holistic digital tool capable of measuring the CEP of built assets. By doing so, we aim to cover both methodological and technological gaps, which are identified as critical barriers to advancing CE principles in the construction industry (Gasparri et al., 2023). In this way, our work aims to contribute to the four most important sub-clusters within the gaps as identified by Gasparri et al. (2023): design, policies/standards, assessment method and digitalisation.

Assessing the value of a built asset at its end of life (EoL) or end of use (EoU) is particularly complex. We refer to EoL and EoU as described in Murakami et al. (2010); however due to the more complex user arrangements of built assets compared to other commodities, we will adapt these terms for the construction industry in the discussion (section 5). Built asset lifetimes are generally long and unpredictable, demand for construction materials and components depends on the broader urban context, and there is often insufficient information about disassembly procedures, as well as the condition and performance of constituents. Moreover, different sub-parts of a built asset have different lifespans. Although various measurement and certification methods exist, they are typically limited on specific objectives and EoL scenarios, resulting in a lack of holistic assessment. These methods promote best practices for a certain CE objective, while other practices relevant for the CE are often excluded.

1.3 STRUCTURING THIS PAPER

This paper proposes a set of three key objectives that together holistically and effectively represent the ways in which built assets can influence the CE: longevity, reusability and transformability. Effectively, in this context, means that numerous end-of-use and end-of-life strategies relevant for the CE are represented by three objectives that consider a limited set of factors affecting the CEP for built assets.

We introduce these objectives in the following sections. The background section outlines existing CE objectives and the main challenges associated with applying CE principles in the construction industry. The methodology section presents how we developed and tested the novel holistic set of objectives for CEP assessment of built assets in this study. In the findings section, we formally present our novel system centred on the three objectives for implementing CE principles in built assets. Finally, the discussion connects the findings to our future research directions.

2 BACKGROUND

2.1 CE STRATEGIES FOR BUILT ASSETS ARE INCONSISTENT WITH EACH OTHER

The literature reveals various CE goals for built assets and their constituents. These goals are sometimes referred to as dimensions, types, aspects, or actions, but they all describe strategies articulating CE practices, particularly at the EoU of the built asset. For clarity, we will refer to the various goals described in literature as CE strategies, to distinguish them from our new proposal consisting of a set of three objectives. Durmisevic (2015) identifies three dimensions of transformation by design that determine strategies across different asset tiers of a building: building transformation (adaptability on building level), system transformation (reconfiguration, reuse, repurpose), and material dimension (upcycling/ downcycling). Durmisevic (2015) also highlights "design quality" or "prevention by design" as a key factor influencing the future building value, emphasizing how psychological factors and the importance of place influence the sustainability of buildings. The Circularity Gap Report for Holland identifies four groups of CE strategies, referred to as "scenarios", each with a different impact on the labour market (Circle Economy & Metabolic, 2022). The scenario most relevant to the design of built assets includes three strategies: "design to reduce", "design for cyclability" and "design to last". The scenarios focus on different effects on the labour market; therefore, the strategies are not necessarily mutually exclusive or exhaustive across the scenarios.

The EU waste hierarchy (Directive 2008/98/EC, 2008) outlines five waste management strategies: prevention, preparing for reuse, recycling, recovery, and disposal. The hierarchy recognizes construction and demolition waste as the priority resource stream, and aims to reduce its disposal. The EC has developed a tool to measure CE principles in buildings, called Level(s) (Directorate-General for Environment, 2025). This tool includes indicators for efficient and circular material life cycles, such as the use of: (a) bill of quantities, materials and lifespans, (b) construction and demolition waste and materials, (c) design for adaptability and renovation, and

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(d) design for deconstruction, reuse, and recycling resource. Another EU agency publication emphasises importance of reuse of the existing building stock, listing three circular renovation actions: increasing lifespans, reducing material consumption, and making use of new generation materials (European Environment Agency, 2022). According to Hakaste et al. (2024), durability, adaptability, and reusability (including deconstruction) are crucial CE strategies influencing a building's lifecycle performance. These three strategies contribute to the CE in different ways. Reusability and deconstruction include three additional strategies: ease of disassembly, ease of reuse, and ease of recycling. Each of these strategies requires specific design considerations and dispositions.

Bertino et al. (2021) identify four EoL strategies for buildings: maintenance, refurbishment, demolition, and deconstruction. Additionally, they outline four deconstruction strategies for a built asset: reuse of the entire building (relocating it to a new site), components reuse in other buildings, material reprocessing, and material recycling. Similarly, Marsh et al. (2022) propose CE strategies for concrete, including design for durability, component reuse, and material recycling.

From this diverse body of literature, it is evident that the CE strategies identified across various works lack a unified structure and are not consistently aligned.

2.2 CE IN CONSTRUCTION INDUSTRY SHOWS CHARACTERISTIC CHALLENGES

This subsection lists how we summarized characteristic challenges of implementing CE principles in the construction industry from diverse research work. The list presented here is not exhaustive; more comprehensive literature reviews on the barriers and gaps in the CE application can be found in sources such as Charef et al. (2021) or Gasparri et al. (2023). The challenges highlighted in this subsection are specifically relevant to the quantification of CEP in the construction sector. The following challenges, drawn from the literature (more detailed reasoning can be found in Sibenik et al. (2025)), will guide the novel proposal of CE objectives presented in this work:

Current practices:

- Destructive demolition: common practice, often arbitrary, but faster and cheaper (Bertino et al., 2021)
- Current building stock: most existing buildings were not designed with EoL scenarios in mind (Bertino et al., 2021; European Environment Agency, 2022)

CE flows:

- Avoiding demolition: retaining structures has significant potential for greenhouse gas (GHG) saving (European Environment Agency, 2022; Moisio et al., 2024)
- Building components configuration: simpler, reusable, and deconstruct-able constituents are preferred (Bertino et al., 2021)
- Building adaptability: this is a widely recognized CE strategy (Eberhardt et al., 2022)
- CE flow of components: reuse in their original form is desirable (Ossio et al., 2023)
- CE flow of materials: recycling is the most common practice (Marsh et al., 2022)

Quantification:

- Prioritizing powerful CE strategies: strategies beyond recycling and recovery should be prioritized for greater impact (Morseletto, 2020)
- LCA calculations: these often focus on downscaling and may not capture the full CEP (Ossio et al., 2023)
- Transportation performance at EoL: evaluating transportation impacts requires numerous assumptions, complicating assessments (Moisio et al., 2024)

3 METHODS AND DATA

The objectives of CEP assessment represent various approaches to evaluating the value of building constituents after their primary use has ended and their purpose changed. This study posits three objectives for a holistic CEP assessment and demonstrates their application. The objectives are informed by reviews, case studies, and reports, as well as by the CEP framework previously proposed by Sibenik et al. (2025). Additionally, we outline factors that influence objective-based performance of built assets, including essential considerations for future calculation.

A previously conducted review of quantification methods (Sibenik et al., 2025) serves as the starting point. The CEP framework it introduced comprises three key elements that collectively shape the CEP of a built structure.:

1) Design strategies: the interdependencies between constituents, particularly combinations of their geometrical and topological properties, significantly influence the CEP and the methods used for its measurement.
2) Asset tiers: the hierarchical partitive relationships within a built structure, from the entire built asset to the material tier. By considering multiple tiers, individual and combined performance calculations determine the overall CEP.
3) CE flows: transitions between uses and lifecycles, meaning changes in primary use or location, involve diverse strategies for new purpose of all constituents of built asset. These strategies have varying environmental performance, particularly regarding their GHG emissions.

In addition, we incorporated additional analyses focused on works specifically determining the CEP of built assets. Such works often address the topic without necessarily providing a quantification method or naming the objectives of the potential to be measured.

By critically reviewing existing trends in the literature and employing deductive reasoning, the present study proposes three CE objectives. Initially, the system of three objectives was tested through examples related to the design strategies of built assets, each tier of the asset, and various end-of-use strategies. This test evaluated the system's scope of application and its holistic nature.

Subsequently, the objectives were tested in three descriptive test cases:

(1) Adaptation potential: focuses on quantifying the potential to adapt building configuration; the adaptation potential test case is identified from the literature review (Sibenik et al., 2025),
(2) Temporary work components: this use case investigates the CEP of temporary work components such as formwork; it is explored as part of our research project and rarely addressed in the existing literature (Tizzani et al., 2023).
(3) Materials passports: this use case uses the set of objectives with the intention of creating a materials passport; it is a widely recognized approach used to calculate and document the materials and components within a building (Honic et al., 2019).

These illustrative use cases were selected to represent a range of applications and challenges within the CE framework. The examples were discussed and analysed through meetings and workshops within the with the authors and one other CE researcher, providing insights into the applicability and robustness of the proposed objectives. The team of this project, called Circular Future Cities, explores different aspects of implementing CE in the building sector (ETH Zurich, 2025).

4 FINDINGS

4.1 CE OBJECTIVES ARE LONGEVITY, REUSABILITY AND TRANSFORMABILITY

We observe that while different CE objectives are frequently applied together, existing methodologies typically focus on specific aspects, such as materials passports or LCA. As a result, current CE calculations often fail to encompass all critical circularity aspects of a built asset, especially the challenges listed in subsection 2.2. Our proposed set of three CE objectives consolidates methods for different design strategies and asset tiers into a unified system.

We set the boundary conditions for the novel system unifying the CEP objectives, which needs to be:

- Holistic – all common CE flows are considered by the system and it can be applied to any type of built asset and its sub-parts.
- Measurable – all objectives will provide a numerical value describing the performance of any building or its sub-parts.
- Simultaneous – objectives can be implemented simultaneously within a single built asset, as constituents often intended for different CE flows.
- Compatible – results of objectives can be quantified individually, but then they can be combined into a single comprehensive result.
- Inclusive – not limited to high-performing elements or those specifically designed to meet a particular objective. Instead, all building constituents can be assessed, with their circularity performance reflected as a positive or negative value.

The integrative approach considering various CE objectives represents a novel contribution. Although this research paper cannot be separated from the framework and literature review (Sibenik et al., 2025) and the CEP calculation tool currently under development, it establishes the link between the two and explains the main solution that addresses the challenges identified in the assessment methods. The findings lead to the three objectives that should be targeted during the design of a built asset, but can also be used to evaluate assets not explicitly following the objectives. These three CE objectives and their relationships are depicted in Figure 1 and defined and elaborated upon below. Examples of typical assets, across all asset tiers, which can be calculated with specific objectives are represented in Table 1.

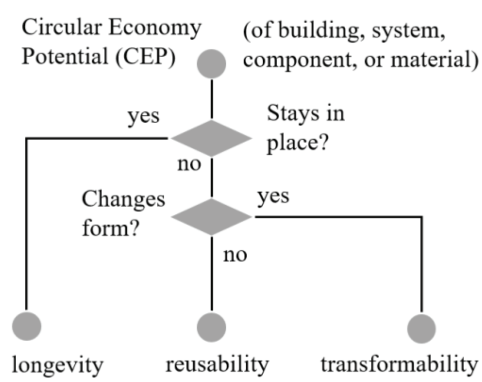

Figure 1 Graphical diagram representing relations between the CEP objectives based on their features

4.1.1 Longevity

Longevity is the objective to keep constituents of a built asset where they are currently located in space, maximizing potential timespan, while continuing to meet existing or changing performance requirements. This objective applies to all constituents of a built asset intended to remain in one place over time. It is closely associated with design strategies such as adaptability, maintainability, and flexibility. Buildings with open and

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flexible floor plans often align with this objective. The constituents following the longevity objective may be considered a fixed asset in economic terms, however, with a significantly longer lifespan than one year. Achieving longevity requires specific design considerations to ensure buildings, systems, components or materials are durable, easily accessible and can meet changing future needs. Longevity is assessed individually for each component; however, the assessment must also be performed at the system and building tiers to provide overall results.

Table 1 Examples of "built structure units" that are likely to perform well for particular objectives

	Longevity	Reusability	Transform-ability
Building	Keeping a building	Moving a building	Demolishing a building
System	Over-dimensioned structural system	Kit-of-parts for partitioning walls	HVAC system
Component	Concrete column	Steel beam	Heat Pump
Material	Concrete	Gravel for surface cover	Coolant

4.1.2 Reusability

Resources that do not remain in place (i.e. outflows into the CE) are distinguished according to their further use. Outflows that retain their form and embodied value are represented with the reusability objective. Outflows that are transformed into another form follow the transformability objective.

Reusability is the objective to maximally retain the original functional performance of a building sub-part after extracting it from its location in space. In economic terms, reusability can be considered a movable asset. The reusability objective focuses on constituents created for dispositions like design for deconstruction, modularity, prefabrication, and the use of standardized constituents adaptable to various contexts. Constituents that score well in reusability should meet the following criteria: enable damage-free deconstruction and detachment, be easily accessible, maintain their value and functionality after deconstruction, requiring minimal repair or improvement, retain generic functional properties suitable for reuse, and exclude significant changes in embodied emissions for new use, aside from transportation and storage impacts. Reusability assessment can be calculated for individual components and is less dependent on the system and building tiers; however, the reusability still needs to include assessments of accessibility and deconstruct-ability. Some external factors like market value or technical requirements might also affect reusability; assessing such factors are out of our scope as they rely on more speculative methods.

4.1.3 Transformability

Transformability is the objective to minimize the additional GHG emissions when a constituent changes its state and is transformed in such a way that it remains a part of the CE, even if changing its intended use. The transformability objective addresses outflows that undergo changes in form and embodied GHG value. In economic terms, transformability can be seen as aggregate asset. It includes widely practiced circularity practices such as recycling, incineration, upcycling or downcycling, and even biodegradation. The effectiveness of these practices varies significantly and is seldom quantified and compared with other transformability options. To achieve a high score in transformability, energy or GHG emissions invested must be kept low. The calculation compares input and output GHG levels for a likely EoU transformation and considers the state-change activities. Relevant design strategies at the component tier include ease of deconstruction and accessibility, similar to reusability, which also require consideration of higher asset tiers. A typical example of transformability at the building tier is demolishing a building, where the resulting GHG values are compared to the initial ones, accounting for all activities in the process. This objective at the building tier resembles material flow analysis calculations.

4.2 OBJECTIVES CONSIDER ALL ELEMENTS OF THE CEP FRAMEWORK

While the proposed objectives should encompass all elements of the CEP framework presented by Sibenik et al. (2025), their application yields varied results depending on the context. To enhance understanding, the objectives are tested with all elements of the framework and use cases.

The design strategies outlined as circular building adaptability determinants by Hamida et al. (2023) are listed and aligned with the proposed objectives, as illustrated in Table 2. These strategies have varying relevance on the objectives, highlighting their interdependencies. Design strategies for each construction asset tier are analysed for their suitability for specific objectives, revealing that some tiers align more closely with certain objectives while others are better suited to alternative objectives.

These objectives are also contextualized within lifecycle '9R' CE strategies described by Circle Economy & Realdania (2025). The CE strategies show a hierarchical order with "refuse" being the most circular and "recover" the least circular. We evaluate CE EoU strategies within the context of the objectives, aiming to encompass all types of circular strategies. The strength of their alignment is detailed in Table 4.

Table 2 Probability of relevance of design strategies for CE objectives (A-always, S-sometimes, R-rarely, rest N.A.)

Design strategy	Asset tier	Longevity	Reusability	Transform-ability
Flexibility	building	A	R	
	system	A	A	
	component			
	material			
Deconstruct-ability	building		A	R
	system	S	A	S
	component	S	A	S
	material	S	S	S
Multi-usability	building	S		
	system			
	component			
	material			
Regularity	building	A	S	S
	system	A	A	S
	component	S	A	S
	material	R	A	S
Convertibility	building	A	S	S
	system	A	S	S
	component	R	R	S
	material			S
Reversibility	building			A
	system			A
	component			A
	material			A
Maintain-ability	building	A	A	R
	system	A	A	R
	component	A	A	R
	material	A	A	R
Recovery	building	S	S	
	system	S	S	
	component			R
	material			R
Scalability	building	A	A	R
	system	A	A	R
	component	A	A	R
	material	A	A	R
Refit-ability	building	S	R	R
	system	S	A	R
	component	S	A	R
	material			

Table 3 Strength of alignment of CE EoU strategies with particular CE objectives for built assets

EoU strategy	Longevity	Reusability	Transform-ability
Refuse	Strong	Weak	Weak
Rethink	Strong	Strong	Weak
Reduce	Strong	Strong	Strong
Reuse	Weak	Strong	Weak
Repair	Strong	Strong	Weak
Refurbish	Strong	Strong	Weak
Remanufacture	Weak	Weak	Strong
Repurpose	Weak	Weak	Strong
Recycle	-	-	Strong
Recover	-	-	Strong

4.3 USE CASES COMBINE MULTIPLE OBJECTIVES

Applying our three proposed objectives to three use cases (adaptive reuse, temporary work components, and materials passports) reveals that all cases involve multiple objectives (Figure 2). By applying our proposed objectives to these three use cases, we demonstrate the applicability and coverage of our set of objectives. As this paper reports on the conceptual development of our CE objectives, the use cases are purely descriptive.

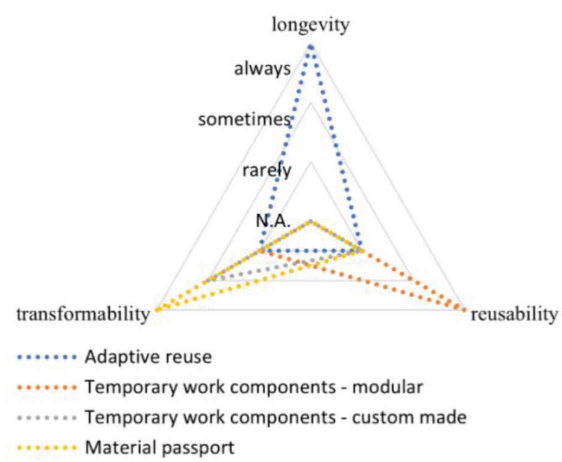

Figure 2 Relevance of objectives for use cases represented in a radar chart

4.3.1 Adaptive reuse

Adaptive reuse has been examined in multiple studies, with additional details in our previous work (Sibenik et al., 2025). This approach assesses the extent to which an entire building can be adapted, focusing on prolonging its lifespan as a whole. However, adaptive reuse is not limited to the longevity objective alone. The asset tiers considered include systems, components, and materials, besides the whole built asset.

A typical case of adaptive reuse is that certain systems align with the longevity objective, such as structural or façade systems. However, other components are rarely accounted for or quantified. In the proposed set of three

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objectives, all parts of the built asset—including those that do not follow the longevity objective—are considered. This means that a building is not quantified for adaptive reuse as a whole, but separately for each objective. All constituents are calculated for a specific objective and have their own CEP score. Some systems will be reused in the same place, therefore score best with longevity, while others elsewhere, and calculated for reusability or transformability objectives. The removable constituents also contribute with their CEP score to the final score of the asset. Depending on the objective, different calculation methods are applied, generally combining elements of existing methods from Sibenik et al. (2025) and considering different design strategies for different objectives.

This comprehensive approach provides a CEP for both existing and novel buildings, surpassing current adaptive reuse methodologies by considering all constituents, including the ones following reusability and transformability objectives.

4.3.2 Temporary work components

Temporary work components, such as concrete formwork, are considered in this use case (Tizzani et al., 2023). Two common types of formwork construction are on one side modular systems that are used in similar ways multiple times, and on the other side custom-made formwork made on site and discarded after use. The most common material for modular formwork is aluminium, while the custom-made formwork often consists of wooden planks and panels. There are also realizations which combine these two types of construction. Although these realizations of temporary work components are considered typical, it is difficult to measure their CEP with current measuring tools.

Aluminium systems are created with an intention to be used multiple times in the initial form, combined with other elements of the system. They are characterized by a modular and standardized design. Although they can be recycled and they could potentially score positively with the transformability objective, their primarily objective and better score is expected with the reusability objective. Therefore, their score is calculated based on the design strategies relevant to reusability, such as deconstruct-ability and refit-ability.

Wooden formwork created on site corresponds better to the transformability objective, as custom made, and it is commonly used in another form after the EoU. Therefore, the system can be calculated for the CE strategy which is likely to happen, such as incineration or recycling, where the difference of GHG before and after the process indicates its CE score.

In the system including both reusability and transformability, both types of construction can be modelled and calculated, results compared, and the better performing construction selected. Additionally, the CEP score of temporary work components can be added to the CEP score of the entire structure. Existing CEP measurement tools generally do not allow such detailed calculations for formwork or other temporary work components.

4.3.3 Materials passports

Materials passports document the quantities of materials within a built asset, focusing primarily on the material tier of a construction asset. Other tiers are typically overlooked, and configurational properties are considered only in a limited capacity, such as certain properties on the component level. While materials can be evaluated using the proposed objectives, only the transformability objective and material tier are deemed relevant.

Compared to the novel set of three objectives, materials passports focus on the transformability of materials but do not fully address the objectives of longevity and reusability, nor do they account for all construction asset tiers that retain higher embodied GHG value. To calculate a materials passport using the proposed set of objectives, it is necessary to consider the transformability objective and, in some cases, reusability for specific types of materials or components. The results will align in a similar direction, although our calculation and the data used do not fully reflect a materials passport. Relying solely on such calculation is not advised, as it does not consider potentially more sustainable options, such as the reuse of components in their original form (Ossio et al., 2023) and structural durability (Marsh et al., 2022).

5 DISCUSSION

The proposed holistic set of objectives for calculating the CEP of built assets accommodates all elements (design strategies, asset tiers, CE flows) of the CEP framework and supports our three test use cases, some that have not been previously considered in other evaluation methods (temporary work components, removable components of adaptable buildings). The synthesis of the objective-based calculation and elements of the CEP framework is represented in Figure 3. While similar objectives have been widely discussed separately in literature, aligning them within a single set of objectives respecting the boundary conditions of being holistic, measurable, simultaneous, compatible, and inclusive makes a significant step towards a holistic CEP calculation. This integrated approach aims on enabling the comparison of objectives, prioritization of strategies, and a robust assessment of the actual CE behaviour of built assets. The system's adaptability could allow for tailored prioritization depending on regional urban plans—for instance, emphasizing reusability in one area while focusing on longevity in another. However, it is crucial to recognize the interrelated nature of the CE objectives; excluding certain objectives from the assessment could overlook better-performing options.

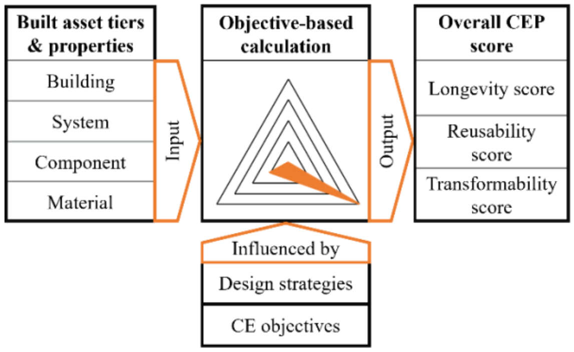

Figure 3 CEP assessment considers all built asset tiers, and it is influenced by design strategies and potential EoU scenarios. It provides results per objective, all contributing to the total CEP score.

All elements of the CEP framework are addressed by at least one objective. The challenges identified in the literature are considered for the novel system of objectives with special attention given to configurational properties of built assets, adaptive reuse with the retention of built assets and outflow of constituents, evaluation of both positive and negative impacts of state transformation, and accounting for both high-performing and low-performing elements.

The set of objectives allows for adapted definitions of EoU and EoL for the built environment. In this context, EoL refers to the point when any asset tier ceases to follow their intended objective, while EoU indicates a change of its role within a higher tier. Therefore, assets following reusability are expected to have multiple EoU points, whereas longevity and transformability have EoU and EoL occurring at the same point in time. Scenarios such as adaptive reuse, following multiple objectives, do not reach EoU or EoL on the building tier, however their lower tiers do.

While promising, this study has limitations. Numerical calculations for the proposed framework are still under development and are not included in this publication. Incorporating and interrelating all the necessary methods could present challenges for some influencing factors of the CEP assessment. Initial tests yielded encouraging results, but acquiring reliable data remains a significant obstacle, as observed in other methodologies like LCA and materials passports. We use available databases for GHG properties, environmental product declarations, and expert assessments to perform the calculation, especially those used by established methods and research when applicable. While we aim to include existing indicators where possible, detailed investigation into data reliability is not part of this study. However, areas in need of improvement will be indicated. A broader range of tests, supported by detailed calculations, is necessary to fully assess the tool's applicability.

Moreover, practical implementation of the approach has not been achieved yet, and the circularity objectives, derived through deductive reasoning, may not be sufficient for all circularity cases. Although the performed tests did not reveal shortcomings, more robust testing could uncover unaddressed issues. These risks will be addressed when the CEP assessment tool reaches higher development level with a more elaborated and diverse set of case studies. Additionally, presenting the framework to the audiences beyond the research team is necessary to assess its adoptability and usability. Receiving feedback from the community actively advancing CE principles in the building sector is particularly valuable.

Future research will focus on developing calculation methods based on the three objectives. This includes creating a tool to measure the CEP and establishing case studies as a proof of concept. All three use cases have been successfully supported by the proposed objectives, and the next steps involve incorporating exact data and realization of a measurement method. This method will subsequently be realized as a decision-support tool working with BIM models. Leveraging BIM-authoring software tools and models is a key goal to expedite the measurement process and identify requirements for a fully automated CEP assessment.

6 CONCLUSIONS

This work proposes a structured organization of CE objectives in a holistic system for built assets, addressing multiple challenges identified in the literature and existing quantification methods. The proposed set of objectives aims to enable a holistic evaluation of the CEP, providing a basis for comparing built assets or their tiers (systems, components, materials), designed with varying objectives or without any. Unifying the objectives relevant for the construction assets is a prerequisite for the development of a new tool. The novelty of this work lies in its comprehensive set of three objectives, which encompasses all relevant design strategies and CE strategies for EoU and EoL, while also considering various asset tiers. Although it is still a work in progress, the solution currently follows all identified crucial boundary conditions of being holistic, measurable, simultaneous, compatible, and inclusive, which, in combination, are still not available in practice.

Developing this objective-based concept as a digital tool will offer a fast and efficient method for assessing the CEP. By unifying approaches that are currently fragmented or separately addressed, the objectives ensure a comprehensive evaluation and allow for the calculation of diverse CE performance metrics within the built environment.

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