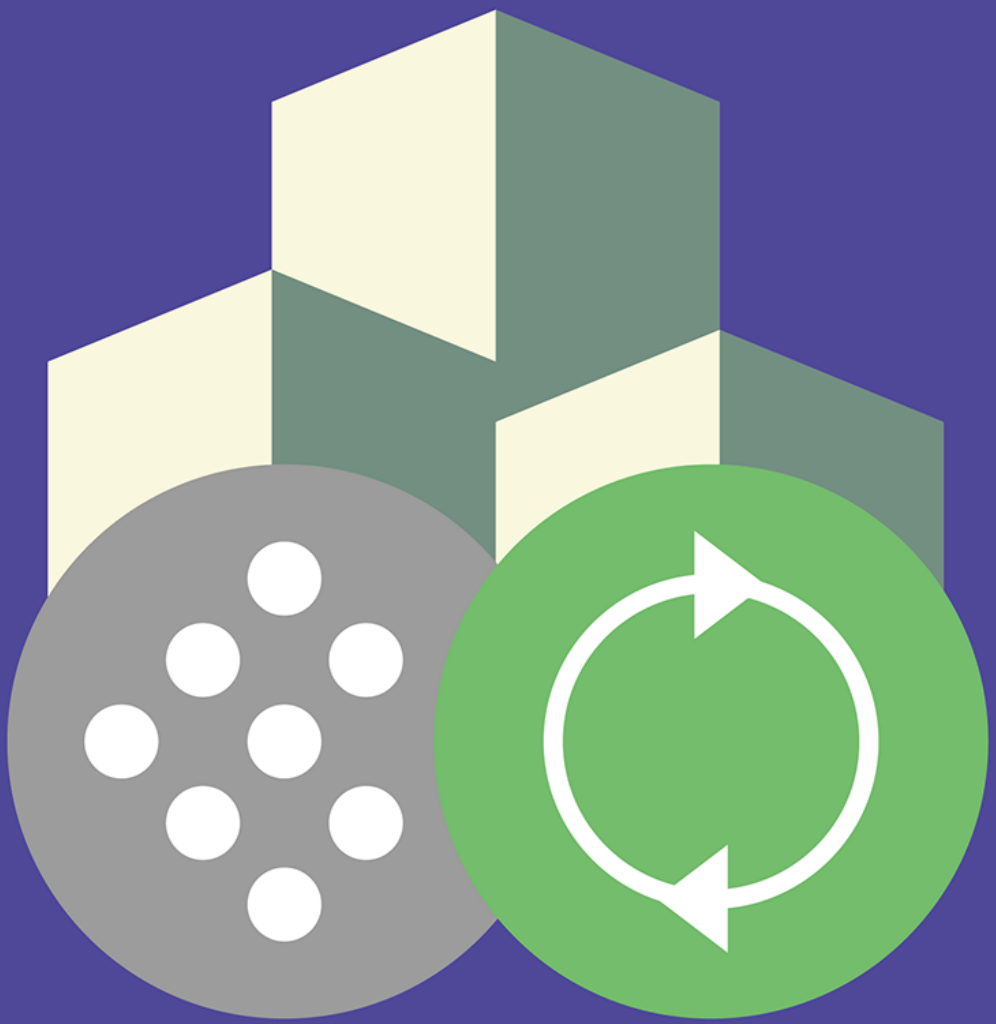
ISSN 1831-9424

European Commission

Circular Technologies in Construction

Putting Science Into Standards



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2024

Joint Research Centre

EUR 31928 EN

Contact information
Name: Dr Andreas Jenet
Address: Rue du Champ de Mars 21, 1049-Bruxelles, Belgium
Email: andreas.jenet@ec.europa.eu
Tel.: +32 229 87187

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC137756

EUR 31928 EN

Print	ISBN 978-92-68-15425-0	ISSN 1018-5593	doi:10.2760/600209	KJ-NA-31-928-EN-C
PDF	ISBN 978-92-68-15426-7	ISSN 1831-9424	doi:10.2760/876431	KJ-NA-31-928-EN-N

Luxembourg: Publications Office of the European Union, 2024

How to cite this report: European Commission, Joint Research Centre, Jenet, A., Lamperti Tornaghi, M., Tsionis, G., Sejersen, A., Moseley, P., De La Fuente Nuno, A., Wrobel, M., Hobbs, G., Guldager Jensen, K., Chevauche, C., Levy, M.H., Osset, P., Denton, S., Ottosen, L., Lynch, J., Lewis, M., Fuchs, M., Mian, L., Maurer, P. and Taucer, F., *Circular technologies in construction. Putting Science Into Standards*, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/876431, JRC137756.

Contents

Abstract

This report emphasizes the importance of standardisation in promoting circular construction and the circular economy. It discusses the need for future standardisation and pre-normative research for circular construction in terminology, metrology, performance characterisation, compatibility and operability assessments. The report identifies several opportunities for synergies, such as collaboration between the New European Bauhaus and analysis the gap analysis carried out by CEN/TC350 on circularity in the construction sector, emphasising of overcoming cradle-to-grave construction frameworks. Strategies to bridge these gaps include enhancing standardisation, collaboration, and innovation. Four strategic areas could benefit from standardisation: a) frameworks and indicators to measure circularity, b) quality assurance of reused and recycled material, end-of-waste criteria, c) design for circularity, adaptability and disassembly, and d) building information. The report also highlights the need for clear objectives, focused standards, cost-effectiveness, common future scenarios, resource indicators, and practical implementation aspects to advance circularity in the construction industry. The recommendations provided aim to guide future standardisation activities, aligning with circular principles to drive industry competitiveness and environmental stewardship. Taking first steps towards a standardisation roadmap, the study highlights specific areas that CEN/TC 350 may consider in their future work programme and suggests high priority topics based on discussions with stakeholders.

Foreword

Over the last ten years, the Putting Science Into Standards workshops have addressed a wide range of topics and brought along innovation in multiple standardisation areas. These workshops enable scientists and technicians to meet policymakers and standard setters to pave the way towards new standards. Putting Science Into Standards is mentioned in the EU Standardisation Strategy (COM/2022/31) and supporting the Annual Union Work programme for standardisation. The initiative is part of NewPolicies (32529) of the JRC Portfolio 33 on innovative policymaking.

This report refers to a workshop organised in 2023 focusing on technologies supporting circularity in construction. It was organised with the support of DG GROW, the New European Bauhaus and was based on the DG RTD's industrial technology roadmap for circular technologies in the European Research Area. The roadmap specified technologies and standardisation gaps to be tackled in the European framework programme for research and hence contribute to the development of the industrial ecosystems highlighted in the European Industrial Strategy.

The aim of the workshop was to explore how recent developments in science and technology can accelerate circularity in construction to reduce waste and enhance competitiveness. This is done by anticipating a series of standards supporting policies for waste management and the construction industrial ecosystem, by bringing involved stakeholders together and encouraging exchange to gather concrete actions for moving forward.

Acknowledgements

A sincere gratitude to all the participants, speakers, and panellists, joining from Europe, and its neighbouring countries as well as from overseas, who took part in the discussions of this workshop. Gratitude also to the CEN Technical Committee 350 Subcommittee 1, and colleagues from the Commission services (JRC and GROW) for their strong support and dedication in the successful organisation of the 2023 Putting Science into Standards workshop.

We thank Salla Saastamoinen, the JRC Deputy Director General, European Commission and Stefano Calzolari, President CEN and Maive Rute, GROW Deputy Director General and Chief Standardisation Officer, for their opening address. For the active participation in the panel discussions our gratitude is directed to Dieter De Lathauwer, (CEN/TC 350), Fernando Sigchos Jimenez (European Builders Confederation), Christophe Sykes (Construction Product Europe), Krzysztof Maruszewski (JRC) and Ashok Ganesh (CEN and CENELEC).

A special thank is extended to the European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardisation (CENELEC), and Danish Standards for their intensive collaboration and efforts in convening meetings and providing technical services. The engagement of the 400 registered participants and the fruitful discussions held at this workshop has helped frame this report. The work and discussions will feed into and guide the future work and development of CEN/TC 350, which aims to provide well-functioning standards in the construction sector.

Authors

Andreas Jenet, Marco Lamperti Tornaghi, Georgios Tsionis, Amanda Sejersen, Philippe Moseley, Arturo de la Fuente Nuno, Malgorzata Wrobel, Gilli Hobbs, Kasper Guldager Jensen, Catherine Chevauche, Mike Levy, Philippe Osset, Steve Denton, Lisbeth Ottosen, Janet Lynch, Martha Lewis, Manfred Fuchs, Livia Mian, Philip Maurer, Fabio Taucer.

1 Introduction

The construction sector plays a vital role in the economy and is the second largest industrial ecosystem in the EU. However, it is important to acknowledge that construction has a significant impact on the environment, consuming up to half of all newly extracted materials and being responsible for over 1/3 of the EU's waste generation, making it the largest single source of waste.

Thus, construction is one of the priority areas in the Circular Economy Action Plan (European Commission, 2020), which aims to facilitate the transition from a linear to a circular model. To move towards a more circular model, it is important to retain more value in the entire construction supply chain, from entire buildings down to materials, and to find innovative ways to make them more environmentally friendly. Additionally, the transition towards a circular model should encompass the entire sector, and stakeholders should collaborate to undertake the transition.

Innovation in the circular construction sector.

Today, there are policies in place that address the environmental impact of construction, such as the Waste Framework Directive (European Union, 2008) and the Construction Products Regulation (European Union, 2011). The ERA industrial technology roadmap for circular technologies and business models in the textile, construction, and energy-intensive industries (European Commission 2023a, 2023b) outlines the technologies and standardisation gaps that need to be addressed in the European Framework Programme for research. This will contribute to the development of the industrial ecosystems highlighted in the European Industrial Strategy.

European research investors are interested in ensuring that innovative technologies resulting from European-funded research actions lead to accelerated market access. Standardisation is a key enabler in this context. European industry and SME innovators are keen to remain at the forefront of standards-setting. They aim to define high-quality standards that meet both European consumer expectations and legislative requirements, ensuring trust in their products.

The workshop aimed to present recommendations for addressing standards in the construction sector that support a cradle-to-cradle approach. This involves a closed-loop system in which waste is minimized. Strategies for achieving this and in which the life cycle of existing materials and products is extended, include sharing, leasing, redesigning, reducing, reusing, repairing, renovating, refurbishing, recovering and recycling existing materials and products (Figure 1).

Reducing the use of raw materials in concrete production and limiting landfill areas aligns with the Sustainable Development Goals for sustainable resource consumption and production in cities, as well as for mitigating climate change (Tazi et al., 2021). However, construction regulations are fragmented and influenced by European, national, and local laws. Therefore, effective coordination is crucial.

Standards are essential for the transition to a circular construction sector. They provide safety, consistency, and reliability. Additionally, standards are a powerful tool for translating science into policymaking, making the EU stronger and more competitive. They serve the industry by facilitating interoperability, avoiding unnecessary complexity, and bringing new technologies closer to the market. Standards must remain relevant and responsive to the accelerated speed of research and the needs of industry and society. This can be ensured by having scientists proactively explore new topics, identify future needs, and deliver standards in a timely manner. The Putting Science Into

Standards initiative brings together stakeholders and researchers to foster innovative ideas and new technologies that could benefit the establishment of standards in the given field.

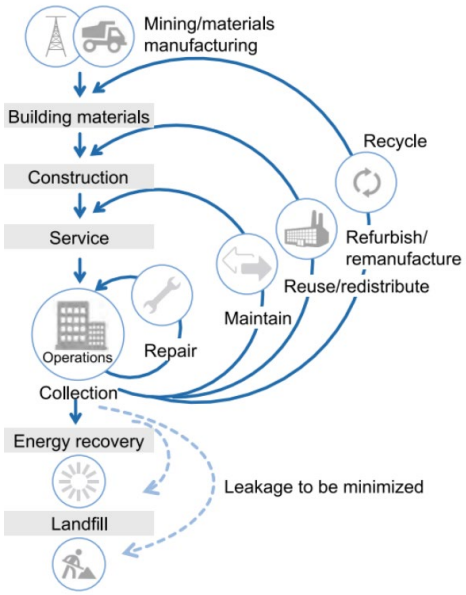

Figure 1 Can the circular economy transform the world's number one consumer of raw materials? (World Economic Forum, 2016).

The European standardisation landscape is currently experiencing a busy period. This is due to the implementation of the CEN CENELEC Strategy 2030 (CEN and CENELEC, 2021), which aims to strengthen Europe's role as an independent facilitator among stakeholders. Additionally, the European Commission's Standardisation Strategy (European Commission 2022b, 2022) is being rolled out, with the goal of ensuring that standardisation serves as a driver for Europe's competitiveness and resilience. Finally, the Code of Practice on Standardisation was published in March 2023, with the aim of helping to integrate research activities in standardisation (European Commission 2023b, 2023a). Furthermore, the newly established High-Level-Forum for Standardisation aims to accelerate the adoption of standards by the market, introducing confidence and trust in users. In addition, a Transition Pathway for Construction was published in March 2023 as part of the updated EU Industrial Strategy (Papadaki et al., 2023). The pathway outlines a vision and action plan for a more digital, green, and environmentally friendly construction ecosystem. To achieve this goal, the European Commission, member states, and industry must work together. This workshop promoted collaboration among stakeholders by linking research and standard setters.

Putting Science Into Standards workshops

Over the last ten years, the Putting Science Into Standards workshops have addressed a wide range of topics and brought along innovation in multiple standardisation areas. This shows the great value of the Putting Science Into Standards initiative, where scientists and technicians meet policymakers and standard setters and merge their fields of expertise, to pave the way towards new standards. The aim of the 2023 Putting Science Into Standards workshop was to explore how recent developments in science and technology can accelerate circularity in construction and enhance competitiveness. This was done by anticipating a series of standards supporting the related legislation, by bringing stakeholders together and encouraging exchange on concrete actions to move forward.

The 2023 PSIS workshop brought stakeholders from research, scientific and standardisation communities together with policy makers to exchange views on standardisation needs for implementing circular technologies in the construction sector. The objectives of the workshop were to:

— specify circular principles to facilitate the transition to a more sustainable circular economy in the construction ecosystem, covering design to de-construction and end-of-life scenarios in all stages of current and subsequent life cycles.

— reflect on the findings of the gap analysis developed by CEN/TC 350/SC 1 “Circular economy in the construction sector”.

— collect additional stakeholders’ needs to complement the gap analysis and define future standardisation priorities.

— encourage participation of the scientific community into future standardisation activities.

The workshop included sessions that harvested feedback on gaps, good practices at national level, and research results on:

— framework, definitions, indicators, measurement, and assessment

— quality assurance of reused and recycled material, end-of-waste criteria

— design for circularity, adaptability, and disassembly

— buildings information: data format, management, and storage.

2 Needs for future standardisation

Policies for circular construction

The EU construction industry is with 35% of the EU's total waste generation, with construction and demolition waste being one of the most significant waste streams, the single biggest source of waste in the EU. It also accounts for almost 10% of the EU's Gross Value Added (Eurostat 2023). Therefore, it is essential to act on circularity in construction to make sure we meet the goals set by the European Green Deal and the Paris Agreement and support the Circular Economy Action Plan. The plan aims to reduce the EU's residual waste by 50%. In this regard, and considering the updated EU Industrial Strategy, the European Commission proposed the Transition Pathway for Construction.

As the primary policy document on construction at the EU level, it was co-created together with the industry, member states and other stakeholders. It presents a vision for the construction ecosystem to undergo a green and digital transition and to improve its resilience and sets out an actionable plan. In terms of legislation, the Construction Products Regulation (European Union, 2011) is currently being revised to improve the single market for construction products and to integrate environmental criteria. This will stimulate a circular economy in construction and improve the competitiveness of the industry. The standards developed under the framework of the Construction Product Regulation are currently being revised and will include product information covering the whole life cycle. Standards play a crucial role in shaping our world, influencing the way we design and use our buildings and transportation, produce, and consume our food, provide healthcare, and interact with our environment. Standards can be a useful tool for translating scientific findings into policy decisions.

The uptake of circular economy in the construction sector appears to be influenced by policies that are scattered across various areas, ranging from the Waste Framework Directive (European Union, 2008) to the Construction Products Regulation and product standards. Additionally, national, and local regulations further complicate the landscape, particularly with regards to waste. Given this highly fragmented framework, effective coordination is essential.

A 2050 roadmap to reduce the whole life cycle greenhouse gas emissions of buildings is being developed together with a certification scheme for carbon removal from construction products. Numerous economic activities relevant to construction, including renovation, demolition and the circular use of products, feature in the EU taxonomy for sustainable activities (Regulation (EU) 2020/852). Moreover, various studies are being conducted on circular approaches to construction including end of waste criteria, indicators, and updated guidance. There are also activities looking at the digital transition, which is an important enabler for the circular economy. This includes support for the digitalisation of the built environment, public procurement and SMEs in construction, as well as development of an EU framework for digital building logbooks. To implement all the recommendations and activities outlined in these policy initiatives, there is a need for common understanding and agreed methodologies, and here standards are needed.

Research and innovation in circular construction

The European Research Area industrial technology roadmap for circular technologies and business models (European Commission 2023a) shows that EU companies in the construction ecosystem are particularly strong in implementing established technologies, while overall less active in technologies at R&D stage. This demonstrates that inputs from research and innovation activities are key for the development of future standards supporting a sustainable transition of the construction sector.

Industry has driven innovation on some aspects of circularity in the construction sector, from processing of waste materials for secondary raw materials to systems that were proven in an operational environment (Technology Readiness Level (TRL) 9). However, the market is still unable to take advantage of these innovations partly due to the lack of a clear and regulated framework including standards. Research in other aspects, such as design for adaptability, reuse, and deconstruction, is at an early stage: basic concepts and a common language are being formulated, and indicators are still being developed (TRL 2). Within this broad spectrum, research must support the development of the most embryonic and innovative research areas, while standardisation must create the conditions for the benefits of innovation to be transferred to the society and citizens.

Among the more than 80 Technical Committees in CEN/CENELEC that are active in the construction sector, Technical Committee 350 is dealing with sustainability of construction works and recently produced a gap analysis as prioritisation exercise for future work items in the field of circular economy. At the international level, the scope of ISO Technical Committee 323 covers frameworks, guidance, supporting tools and requirements for the implementation of activities of all involved organizations, to maximize the contribution of circular economy to sustainable development.

Terminology and indicators to monitor circular economy

The European Commission and Eurostat have established a framework to monitor progress towards a circular economy using available statistical data. This framework focuses on aspects of the circular economy related to resource use and waste management. However, it is important to note that aspects related to maintaining the value of products and materials for longer, such as design for circularity, repair, and reuse, are not yet included in this framework.

Implementing this framework will necessitate significant changes to our production and consumption models, as well as a shift in our perception of resource usage and disposal. Additionally, it will require the adoption of new consumer behaviours, such as car sharing instead of individual vehicle ownership.

The EU has established a few circular economy objectives as part of its Circular Economy Action Plan that aims to double the circular material use rate. Statistics allow to monitor the transition towards circular economy. The EU circular economy monitoring framework is one of the initiatives of the European Commission's Circular Economy Action Plan from 2020. The framework comprises 11 indicators, representing mainly macro-economic data, providing a balanced picture between environmental and economic aspects of the circular transition. These indicators are organised in five dimensions: production and consumption, waste management, secondary raw materials, competitiveness and innovation, and global sustainability and resilience. The indicators use readily available data such as total material consumption, waste generation, and recycling rates. The EU monitoring framework is broad and seeks to capture the whole economy, but there are a few indicators related to construction. The incorporation of more specific indicators for the construction sector would be complementary and would require a framework with a narrower scope.

When discussing circularity statistics, it is important to consider how to report the information and which department(s) in the business would be responsible. It is also important to keep in mind that some aspects of circularity, such as remanufacturing, are harder to measure than others, like recycling. Additionally, sometimes an indicator about a non-observable or hard-to-observe fact can only be measured indirectly. For example, secondary waste - the residual waste generated during the recycling process - is typically measured indirectly. Measuring circularity in design and technology is generally more challenging than measuring circularity in material flows. Important steps towards achieving this include introducing a digital product passport and developing clear

definitions and standards. A successful collaboration between statisticians, researchers, and scientists is crucial to combine skills and share information, ultimately improving circular economy metrics.

Linking the work of the New European Bauhaus to circular construction

The New European Bauhaus is an environmental, economic and cultural initiative launched in 2020. This initiative was created by the European Commission together with stakeholders. Its goal is to be an accelerator of the European Green Deal and aims to make the European Green Deal more tangible to the citizens, showcase a positive future through projects and bring like-minded people together. It is defined by three values: sustainability, reflecting harmony with nature and our planet; aesthetics, reflecting an experience inspired by art and nature; and inclusiveness, reflecting the connection between disciplines, cultures and ages. It follows three working principles: participatory processes, multi-level engagement locally and globally, and transdisciplinary approaches to problems.

The New European Bauhaus implements and develops supporting actions, including the development of standards and guidelines, to assist projects. One of the tools within the standardisation action is the Compass. It provides guidance for actors who wish to apply New European Bauhaus values to their activities, working with levels of ambition for each of the values. The project aims to achieve sustainability by repurposing the three levels and closing the loop to reach net zero in the entire value chain. The three levels are sustainability (from climate goals to circularity, zero pollution, and biodiversity), aesthetics (as the quality of experience and style beyond functionality) and inclusion (from valuing diversity to securing accessibility and affordability). Furthermore, the project aims to achieve regeneration by giving back more than it takes from nature, extending to the entire industrial context. The first two levels can be linked to the topic of circular construction. The New European Bauhaus movement adds a cultural layer of inclusiveness and aesthetics to the discussion on circular economy.

The New European Bauhaus also aligns with Level(s), a framework developed by the European Commission to assess and improve the sustainability performance of buildings (Dodd et al. 2017). Level(s) provides a common language for measuring and benchmarking the environmental, social, and economic aspects of building construction and operation. Together, the New European Bauhaus and Level(s) signal a commitment to reshape the future of construction and design by prioritizing sustainability, circularity, and community engagement in the built environment (European Commission 2022a).

Gap analysis on circularity in the construction sector

A gap analysis on the standardisation landscape of circularity in the construction sector was conducted by CEN/TC 350. The work was initiated by CEN/TC 350/SC 1 who set up a working group to explore the priorities for standardisation work relating to circular construction. The gap analysis work concluded with recommendations in terms of future prioritization of standardisation items. The gap analysis work was divided into nine focus areas to consider the whole range of aspects that are important for circularity in the construction sector. These focus areas included the framework and definitions, indicators for circularity, data storage and maintenance, planning and design, circular procurement, resources at the construction sites, operation and maintenance, the end of use phase and circular business models. The aim was to get an overview of what is already available by looking into existing standards, codes of practice, policies and initiatives. Moreover, preliminary gaps were identified. An extensive consultation process was conducted involving mainly the feedback from national standards bodies. They were asked to provide comments and views on

the identified gaps, additional gaps, areas, or standards to include. A final consultation report with a ranked list of gaps and recommendations was developed and presented in September 2023.

All the preliminary gaps presented as part of the gap analysis work were considered important to resolve in the future to a greater or lesser extent. The highest ranked gaps address the need for re-certification of materials enabling safe use and reuse, more specific frameworks, clearer definitions, differentiating between what is already built and what will be built in the future, and the testing requirements for various reused materials and products. These gaps helped shape the final recommendations, which have been used to steer the topics of this workshop.

The recommendations are divided into five specific areas: framework and definitions, data, measurement and indicators linked to circular economy, requalification and traceability of reused material, testing and certification of recycled products and design for circularity. The recommendations included an initial scope for moving forward to resolve the gaps identified and examples of content for standardisation activities for each area. Additionally, links to related work streams were highlighted to incorporate in standardisation. The current stage involves the discussions and conclusions from five expert-based task groups, who are focussing on each area, including data, assessment, pre-demolition and pre-development audits, reuse, and designing for circularity. These task groups will report back with proposed new work items by June 2024.

3 How to bridge the gap

In this section we provide an overview of the principal platforms which tackle standardisation needs and produce solutions with a global perspective. We discuss how to initiate the circular model, as the transition requires the availability of technological solutions and standards. Standardisation experts were asked to share their experiences in advancing circularity standards in the construction sector.

While the CEN Technical Committee 350 of aims to promote sustainable construction practices, including the integration of circular economy principles, the Subcommittee 1 (SC 1) focuses specifically on the circular economy in construction. Subcommittee 1 set up five task groups dealing with essential aspects of circular construction, such as framework and definitions, building passports, circular assessment tools, pre-demolition audits, reuse of materials, and design for circularity. When discussing circularity in the construction sector, it is crucial to consider how to close the loop and maintain a positive focus on sustainability. This requires rethinking how we produce, use, and reuse products and materials. For instance, the biological cycle can be used to upcycle leftover resources from other industries into construction materials. The technical circle involves using construction elements and materials that allow for efficient assembly and disassembly of structures. This enables the reuse of these elements and materials in high-quality projects.

CEN/TC 350/SC 1 conducted the gap analysis to identify disparities between current practices and circular construction principles. This analysis, informed by scientific evidence, highlights areas that need improvement for the transition to circular construction. When assessing readiness for circular construction, we have identified obstacles beyond the initial findings of the gap analysis. To address these challenges, proactive measures are required to overcome scientific shortcomings in implementation. Standards are crucial in promoting circular construction practices by ensuring compliance across all building aspects. A fast-track mechanism is needed to implement promising products and solutions identified through scientific evidence quickly.

CEN/TC 350's standardisation efforts are proactive, seeking solutions to address scientific gaps. CEN/TC 350/SC 1 has established several Task Groups to tackle specific aspects of circular construction.

- circularity-related aspects of products, materials, and building passports/log-books.
- circularity assessment methodologies.
- pre-demolition and pre-redevelopment audits and evaluations.
- horizontal standard or technical report for the reuse of construction products and materials.
- horizontal deliverables for design for circularity across all construction levels.

These task groups collectively contribute to the ongoing efforts to advance circular economy principles within the construction sector, paving the way for a more sustainable future.

Technical Committee 323 of the International Organization for Standardization is developing standards for the transition to a circular economy. There is a set of three standards, with the first (ISO 59004) focusing on the principles of circular economy and actions to implement it. A second standard (ISO 59010) proposes a way to move from linear to a circular business model. The third standard (ISO 59020) concentrates on how to measure and assess circularity performance. The development of the standards is in the final phase and will hopefully be published in April 2024.

These standards are not specific to the construction sector but are transversal standards defining circular economy as an economic system maintaining a circular flow of resources by recovering, retaining, and adding value to the resources, while contributing to a sustainable development. Actions to decrease the use of virgin resources, minimize waste and close the loops are presented. The transition to a circular economy requires a different mind-set focusing on better collaboration between key players to share the knowledge within the whole value chain. It is also a question of data management and sharing to better design, repair, re-use and remanufacture products, considering the planetary boundaries, and how to integrate long term approaches for the implementation of the circular economy. Regarding the link with construction, considering the ISO 59000 family of standards as a framework is key.

The global operating ASTM Technical Committee E60 on sustainability collaborates with International Organization for Standardization Technical Committee 323 to develop circular economy standards. ISO/TC 323 working groups develop standards to operationalise ASTM E60 standards, including guides and specifications for sector-specific standards. ASTM E60 is currently exploring ways to integrate circularity and sustainability into existing engineering practices. The committee's efforts towards circular construction include incorporating circularity into building performance, specific construction materials, additive manufacturing technologies, and digital supply chain information. The construction industry's building performance encompasses elements, components, means of fabrication, measurements, and predictions. Vertical committees dedicated to specific construction materials, such as steel, cement, and wood, are actively integrating circular economy principles into their work. The Technical Committee on additive manufacturing technologies (ASTM F42) is developing approaches to enable material reuse. This collaboration involves the ASTM Centre of Excellence for additive manufacturing, which aims to align research with standardisation and accelerate the development process. Recently, the Centre of Excellence held a workshop on digitalisation and construction, where participants discussed potential new materials and workflows to reduce carbon footprint. ASTM's digital information on supply chain activity is developing standards to facilitate the sharing of product data and information.

Circularity has a portfolio of standards within the International Organization for Standardization Technical Committee 59 and its Subcommittee 17. ISO 22057 provides tools to integrate environmental assessment in the design phase of buildings and presents a format to deliver statistical data within circular construction. Subcommittee 17 is revising standards to include a circular aspect and address concerns related to circularity in construction. If new standards are introduced, they should be developed collaboratively with European counterparts to create a global framework. It is important to avoid duplicating existing standards and seek alignment in their development across the European and international levels. This text follows the Vienna agreement between the European Committee for Standardisation and ISO. The agreement allows for technical cooperation to prevent duplication of work and reduce the time spent on preparing standards.

The structural Eurocodes[1] are a suite of European standards for the design of buildings used across Europe and beyond. The Eurocodes are the largest standardisation programme of its kind and has a user base of half a million engineers. The suite of standards is currently being updated, to incorporate considerations on sustainability and climate. In this regard, it is important to recognise that the Eurocodes set the requirements for the safety, robustness, and durability of constructions. They do not set requirements for sustainability of structures or for the economic and environmental cost of projects. However, design rules that enable sustainable structures are being incorporated in

[1] https://eurocodes.jrc.ec.europa.eu

the new edition of Eurocodes. Key focus areas include enabling efficient design by minimizing the use of natural resources, accounting for climate change in environmental actions, and retrofitting existing structures to extend their life rather than replacing them. Specific examples of additions on concrete and steel structures encompass recycled concrete aggregates and the design of reclaimed steel components for reuse. The update of the Eurocodes is an exercise of trying to adapt the design phase of structures to help advance the circular economy, while working with other standards as a system and avoiding overlaps.

4 Framework and indicators to measure circularity

The concept of circular economy (CE) represents a shift towards economic systems that prioritize environmental benefits by reducing resource and energy consumption while also addressing social dimensions like fair taxation and increased manual labour. CE, seen as a subset of sustainability, serves as a 'toolbox' to achieve sustainable development goals (11th, 12th, 13th), particularly in sectors with significant environmental footprints such as construction (Brambilla et al. 2019). Standards, so the opinion of most participants in this workshop, have the function to guarantee that everything in a building complies with CE principles, even in the transition to full circular approaches. Overwhelmingly, practitioners believed there are needs to promote better science for standards.

Traditionally, the construction sector has relied on linear resource consumption models, resulting in environmental degradation through excessive raw material use. Initially, sustainability was defined by the three most well-known R principles of Reduce, Reuse, and Recycle. Over time, by joining with new R principles, the three R principles expanded into up to 11 R (Çimen, 2021). Circular Economy offers an alternative approach (Figure 2), focusing on consumption and production efficiency through strategies like reducing, reusing, remanufacturing, regenerating, and recycling materials (Dams et al. 2021).

However, transitioning from a linear economy to CE requires significant transformation across design and construction systems, posing challenges to environmental, economic, and social aspects. Despite ample research on CE in construction, implementation is hindered by social and technical barriers, including limited public awareness and assessment methodologies (Hossain and Ng 2018).

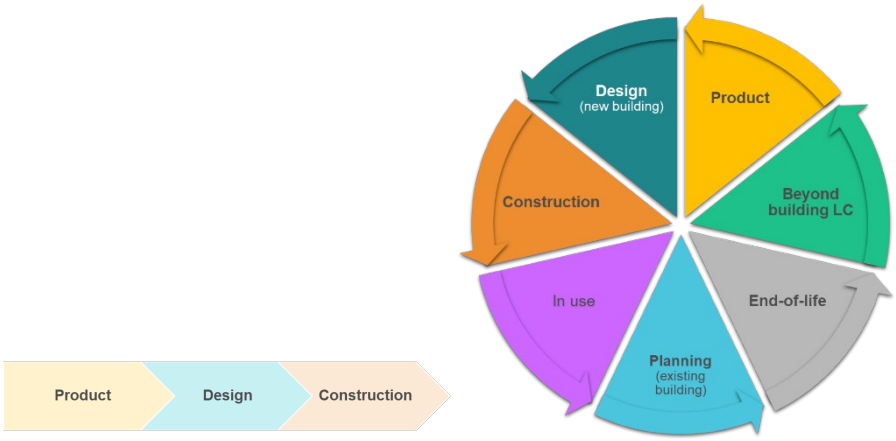

Figure 2 Challenge to move from linear economy to full circular economy (authors concept).

Circular Indicators are important for measuring circularity and tracking progress towards policy implementation and sustainability goals. Standardized assessment frameworks, supported by organizations such as the European Commission and ISO, are essential for efficient measurement and information exchange (Bilal et al. 2020).

Life Cycle Assessment (LCA) tools and data are mainly used in academic circles or by experienced experts. However, challenges such as complexity and lack of comprehensive tools have hindered broader adoption (Pomponi, et al. 2018; Pomponi and Moncaster 2017; Malmqvist et al. 2010). The emergence of standards such as ISO 14040, ISO 14044, and EN 15978 highlights the importance of harmonising sustainability assessment frameworks for buildings. Methods for assessing economic performance, such as Whole Life Costing, are increasingly recognised as effective tools for building owners to evaluate life cycle costs (DS/EN 15643; ISO 15686). Efforts to harmonise and

standardise LCA are necessary to improve accessibility and effectiveness in analysing environmental impacts (Sauer and Calmon 2020; Tazi et al. 2021; Hossain et al. 2020).

Existing research has primarily focused on developing methods. However, there is a need to make assessment tools more widely adopted by building professionals. This can be achieved by addressing end-user needs, providing professional training, and integrating tools into existing workflows, such as Building Information Modelling (BIM) and material selection processes.

To guarantee the success of CE, it is imperative to have a comprehensive understanding of the different phases of a building's life cycle. Level(s) aims to harmonise core sustainability indicators for measuring building performance (Larsen et al. 2022; Díaz-López et al. 2021). However, implementing Level(s) faces challenges such as complexity and lack of self-sufficiency. To overcome these challenges, it is necessary to increase transparency and align with key EU policy initiatives, such as the Renovation Wave, the New European Bauhaus, and the EU Taxonomy for Sustainable Activities (De Wolf et al. 2023).

Nevertheless, there are still vast pre-normative research needs, as in this workshop participants pointed out missing standards for several fields which are yet unsatisfyingly represented in existing frameworks, such as:

- Reuse (9 votes)
- End of waste (8 votes)
- Recertification (4 votes)
- Reuse quality standard (4 votes)
- Recyclability (3 votes)
- Safety aspects (3 votes)
- Design guidance (3 votes)
- Avoiding double counting (2 votes)
- Technical obsolescence (2 votes)
- Multifunctional products (2 votes)
- Procurement (2 votes)
- Sufficiency (2 votes)
- End of waste status (2 votes)

Our survey shows that the biggest gap in pre-normative research for circularity indicators in construction is the lack of methods to measure the quality of products for reuse or recovery, with 42% of respondents identifying this issue. This is followed by circularity for whole buildings versus products, which was identified by 17% of respondents. Additionally, 13% of respondents identified the benefits of reuse and recycling, transparency of materials with reused or recycled content, and boundaries of circularity as areas that require attention.

The assessment of resource use and environmental impacts of products, systems, or services throughout their life cycle, is a scientific- and ISO standardized method, that is increasingly being used in the construction industry.

However, the circular economy requires a rethinking of our current building systems and consideration of their life cycle scenarios for the future. Therefore, it is necessary to reconsider how life cycle assessments are conducted on these building systems. We argue that life cycle assessment, which is a linear approach to environmental impact assessment, does not align with the circular economy concept of multiple product life cycles.

The current approach focuses on pre-production stages such as feasibility, planning, and design and then using raw materials. However, the circular economy requires a new perception of life cycle approaches that shifts our focus from product manufacturing to solution creation. Any building life cycle framework that complies with the circular economy needs to consider economic, environmental, and social dimensions. Despite the increase in published research on circular construction approaches that utilise key principles such as reduce, reuse, and recycle, a life cycle approach to CE building remains absent.

In the traditional linear economy, a building's life cycle begins with a problem-diagnosing phase and progresses through estimation, product design, and construction. The final product, a building, goes through various life cycle stages, starting with the acknowledgment of a need and continuing through feasibility study, product design, construction handover, operation, and disposal. In the Circular Economy, the building life cycle includes stages such as planning, building in use, end-of-life, and beyond building life cycle (Figure 3). The latter involves the various 'R's, such as recycling and repurposing, leading to the new design phase and construction.

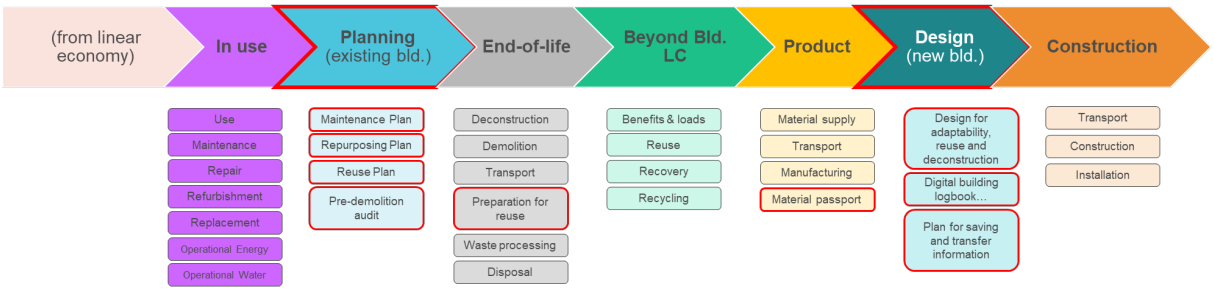

Figure 3 Circular construction life cycle phases following EN 15978 and required for Circular Economy, thus predisposed for standardisation needs.

Main policy interventions, and related standardisation needs, may be vital in the phase of 'planning existing buildings' as with planning the maintenance, re-purpose or re-use, additionally to the pre-demolition audit, new upcoming CE elements arise. Another field for potential standardisation needs is the preparation for re-use during the 'end-of-life' stage, which is a novel element that appeared with the CE approach. During the 'product' life cycle stage, the CE buildings approach necessitates the 'material passport' which is an obvious candidate for future standardisation actions. Harmonised terminology and definitions are necessary to summarise. But also, metrology, including required indicators and measurement procedures need to be consented, in order to make circular construction implementable and less complex (Çimen 2023).

The gap analysis highlighted that in relation to a general framework and indicators to measure circularity in construction, several existing frameworks focus on five performances (Figure 4): 1) technical 2) circularity, 3) environmental, 4) economic and 5) social/health performance. No framework that includes all five performances exists.

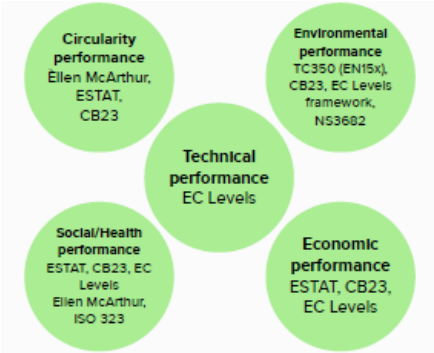

Figure 4 Existing frameworks categorised along five performances

The survey conducted during the registration phase identified significant standardisation gaps, particularly gaps were observed in terminology-related issues, with a subsequent emphasis on performance characterization. In the context of indicators and measurements, the majority of respondents identified metrology issues as the primary gap, closely followed by gaps in terminology and performance characterization. These findings underscore the need for targeted efforts to address terminology discrepancies and enhance performance characterization in frameworks with a focus on metrology issues in the context of indicators and measurements.

Figure 5 Where do you miss standards for framework and indicators?

The identified gaps collected during the session (Figure 5) encompassed various aspects, including indicators for re-use quality, multifunctional products, procurement indicators, re-certification methods, sufficiency measures, strategies to prevent double counting, indicators for technical obsolescence, and concepts for whole (multiple) life.

Overall, terminology lacks definitions related to safety aspects, specifically for material reuse during the 'beyond building' and the design phase (Table 1). There was also a notion that design guidance was lacking and this gap creates a problem for users. In several fields, indicators for the product life cycle (LC) phase but also entire measurement procedures are lacking, related to reuse of materials during the design phase, but also simply indicators for recyclability, detachability, reusability and adaptability of product and materials. Furthermore, a methodology for performance characterisation for end-of-waste or start of a new life is lacking, so the conclusions of the workshop.

Table 1 Prioritised gaps shortlisted by the workshop participants in relation to the circular building life cycle a) use, b) planning (existing building), c) end-of-life, d) beyond building LC, e) product, f) design (new building), g) construction.

Operability assessment	1a	1b	1c	1d	1e	1f	1g
Compatibility (system integration)	2a	2b	2c	2d	2e	2f	2g
Performance characterisation	3a	3b	3c	3d	3e End of waste, start of new life	3f	3g
Metrology (indicators)	4a	4b	4c	4d Reuse	4e	4f Recycling ability Reuse measurement of circular	4g
Terminology & definitions	5a	5b	5c	5d	5e Safety aspects (for reuse materials)	5f Design guidance	5g

Standards, so the 63% of the participants believed, should guarantee that the entirety of a building complies with the concept of circular construction. However still a significant proportion rather saw standards as a vehicle to track the implementation of promising products.

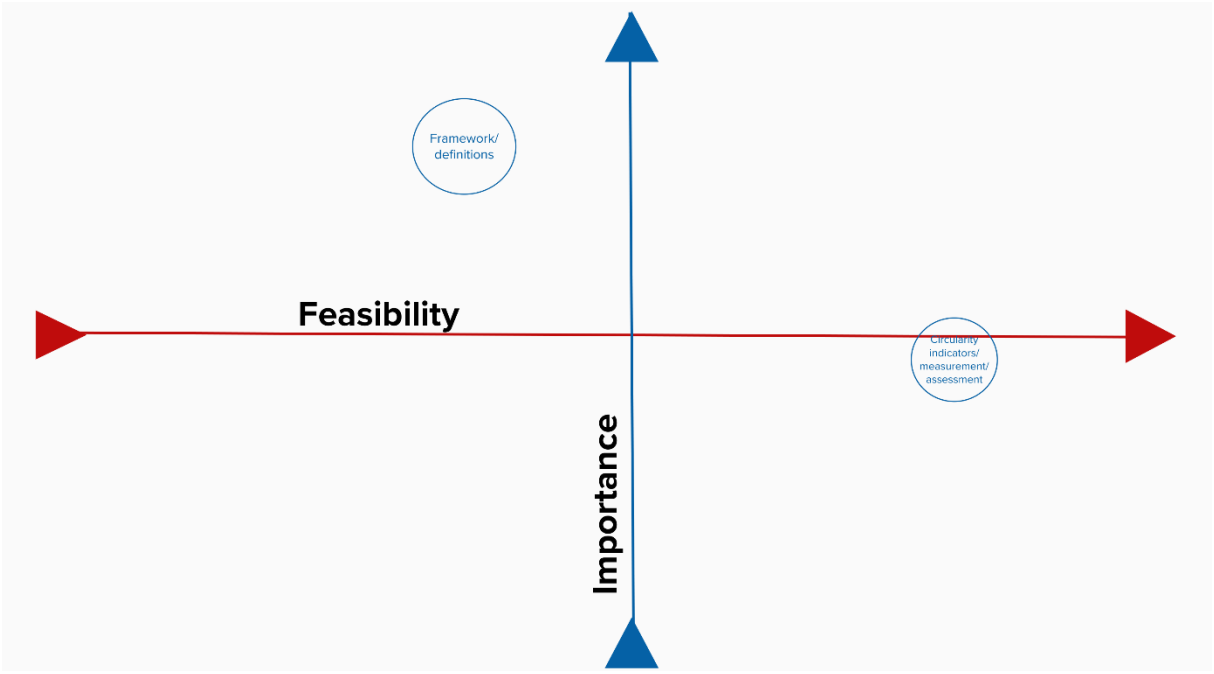

Figure 6 Based on the feasibility and importance of standardisation activities, identified priorities for frameworks/definitions and circularity indicators.

Based on 411 participant entries of the workshop the gap of a missing framework and definitions for circular construction is of high importance (Figure 6). The feasibility to overcome depends on several other circumstances which is expected to lead to time delays. Important, but expectantly soon to tackle are lacking circularity indicators and measurement procedures and assessments. The

workshop received 411 participant entries emphasizing the need for a framework and definitions for circular construction. However, it is important to acknowledge that overcoming this gap may be subject to various circumstances that could potentially cause time delays. Addressing the current lack of circularity indicators, measurement procedures, and assessments is a pressing issue that requires attention. However, participants believed that solutions are at hand.

Nevertheless, there are also pre-normative research gaps for indicators to measure circularity in construction. A total of 42% of the participants believed that methods are needed to measure quality of products for reuse and recover, followed by 17% of participants who missed measurements for circularity of a whole building, remaining participants voted for reuse benefits, transparency of materials and boundaries of circularity.

5 Quality assurance of reused and recycled material, end-of-waste criteria

In the domain of circular construction, a multitude of standards and initiatives are shaping the landscape of sustainable practices. EN 15804, a European benchmark, outlines environmental product declarations for construction services and products, ensuring transparency in environmental impacts. The Buildings As Material Banks (BAMB) project leads a concept shift, advocating for buildings as reservoirs of valuable materials, driving the construction sector towards resource efficiency and circularity. CENELEC's technical specification 50741 underscores circular economy principles for building materials, providing actionable guidelines to bolster circularity in construction processes. Meanwhile, ASTM E3073-22 offers essential guidance on crafting waste management plans for construction projects, crucial for minimizing environmental repercussions. The "GEAR" Guía Española de Áridos Reciclados procedentes de Residuos de Construcción y Demolición offers specialized direction on utilizing recycled aggregates from construction and demolition waste, fostering their circular use. Other initiatives such as the Polish Green Building Council's Guide to Circularity in Construction, the Product Circularity Data Sheet, and France's EPR scheme for construction waste, among others, collectively contribute to steering the construction industry towards sustainability and circularity. These standards and initiatives serve as beacons, illuminating the path towards a future where construction practices are not only environmentally responsible but also resource-efficient and resilient. Further, the Danish project on enabling business by reuse of basic building components focuses on documentation of quality for the second use of building components, facilitating the adoption of reused materials and promoting resource efficiency. The Guidelines for assessing the quality of precast hollow-core floor slabs are followed in Norway (NS 3682:2022), Finland, and the Netherlands, to ensure the quality and suitability of reused construction components, supporting circularity efforts. Another Norway standard prNS 3691 2-3 addresses reclaimed timber, promoting its circular use. To reuse precast concrete elements, ReCreate contributes to a circular economy in construction. A German regulation "Verordnung über Anforderungen an den Einbau von mineralischen Ersatzbaustoffen in technische Bauwerke" from the Ersatzbaustoffverordnung - ErsatzbaustoffV specifies test requirements for incorporating mineral replacement building materials. The Swiss standard SIA 2030 aligns the making of concrete from recycled aggregates, with circular principles. Chilean Norma Chilena Residuos de Construcción harmonises the management of construction waste.

Circular construction has emerged as a critical strategy in sustainable development, aiming to minimize waste and optimize resource efficiency. However, its implementation faces significant challenges due to standardization gaps across various sectors of the construction industry.

Management of construction and demolition waste (CDW) is particularly challenging within circular construction due to the lack of comprehensive definitions and classifications. This gap impedes effective waste management strategies, hindering recycling and reuse efforts. Furthermore, standardization gaps in defining and classifying recycling processes hinder the establishment of standardized procedures and regulations. The regulatory landscape governing reuse practices lacks consistency, hindering widespread adoption and perpetuating a culture of disposability. Ensuring the quality of reused and recycled materials is crucial for structural integrity and sustainability. However, existing standardization gaps in quality assessment and assurance protocols undermine confidence in these materials, limiting their acceptance in new developments. Pollutants in recycled materials, especially composite products, pose significant environmental and health risks due to standardization gaps in assessing and mitigating their impact.

Effective circular business models and enablers are essential for promoting sustainability, but standardization gaps impede consistency across processes and data management, hindering resource tracking and management. While green procurement practices and Extended Producer Responsibility schemes are crucial starting points, the lack of standardized guidelines and criteria poses challenges for both procurers and suppliers. Circular construction emphasizes extending product lifecycles, but gaps in defining criteria for long service-life products hinder the development of circular business models. Standardization gaps in consumer education, product labelling, and waste management impede informed decision-making and participation in circular practices.

End-of-life management is key in circular construction, but gaps in the classification of reuse potential and coherence between pre-demolition, demolition, and post-demolition stages hamper efficient resource recovery. Standardization efforts should focus on seamless transitions between these stages and establishing consented guidelines for waste audits, recycling and reuse inventories. Defining end-of-waste criteria and responsibilities for end-of-life management are crucial, as are clear definitions of repair, refurbish, repurpose, remanufacture, and reuse to guide decision-making. Harmonizing reuse protocols and selective demolition practices is essential for maximizing resource retention. Developing a framework for evaluating the business value from disassembly projects would incentivize circular practices. Requiring end-of-life declarations and environmental product declarations (EPDs) can enhance transparency and accountability in end-of-life management.

Table 2 Prioritised gaps for quality assurance of reused and recycled material, end-of-waste criteria shortlisted by the workshop participants in relation to the circular building life cycle a) use, b) planning (existing building), c) end-of-life, d) beyond building LC, e) product, f) design (new building), g) construction.

 Operability assessment	1a	1b	1c	1d	1e	1f	1g
 Compatibility (system integration)	2a	2b	2c	2d	2e DoP for reusing Expected lifespan Ext prod responsibility (EPR) long service life New business model for GPP std products	2f	2g
 Performance characterisation	3a	3b Reuse measurement of circular	3c Performance of product Performance Criteria	3d End-of-waste criteria Retaining the value not only materials	3e Reuse structural elements Expected lifespan DoP for reusing Quality assessment Legal criteria	3f	3g Safety in use
 Metrology (indicators)	4a	4b	4c Reuse assessment End-of-waste criteria Onsite recycle	4d Onsite recycle End-of-waste criteria Let market to measure the value and not only materials	4e Traceability DoP for reusing Quality assessment	4f	4g
 Terminology & definitions	5a	5b	5c End-of-waste criteria EHS criteria	5d Retaining the value not only materials From cradle-to-grave boundary to cradle-to-cradle	5e New business model for GPP of standardised products (manufactures) Legal Criteria	5f	5g

Participants from the workshop (a total of 411 individuals) recognized the importance of addressing construction and demolition waste. However, they also acknowledged that the feasibility of bridging this gap posed significant challenges. In contrast, the end-of-life of the built environment and maximizing the retention of existing assets were perceived as less crucial. Despite their lower importance, participants expected these aspects to be manageable in terms of feasibility. Additionally, circular procurement emerged as an important consideration, yet its effective implementation remained far from feasible. These insights underscore the delicate balance

between importance and feasibility in sustainable practices within the construction industry, emphasizing the need for strategic planning and collaborative efforts.

When asking 30 experts more in detail (Figure 7) to aspects related to quality assurance of reused and recycled material and end-of-waste criteria, they unanimously recognized the importance of defining when waste materials cease to be considered "waste." Clear criteria are essential for transitioning waste into valuable resources. Experts deemed this aspect feasible and ready to address, signalling a positive step toward circular economy practices. Maintaining responsible quality management throughout the lifecycle of materials emerged as a critical concern. The experts acknowledged that ensuring standards and minimizing waste is feasible. Robust quality assurance practices contribute to sustainable outcomes. Optimizing resource recovery begins before demolition starts. Pre-demolition audits allow for targeted interventions. The experts saw this as a feasible approach, emphasizing its potential impact on waste reduction and material reuse. Assessing material quality and process standards is not only important but also feasible. Rigorous assessment ensures that sustainable practices align with industry norms, as a pragmatic step toward minimizing environmental impact.

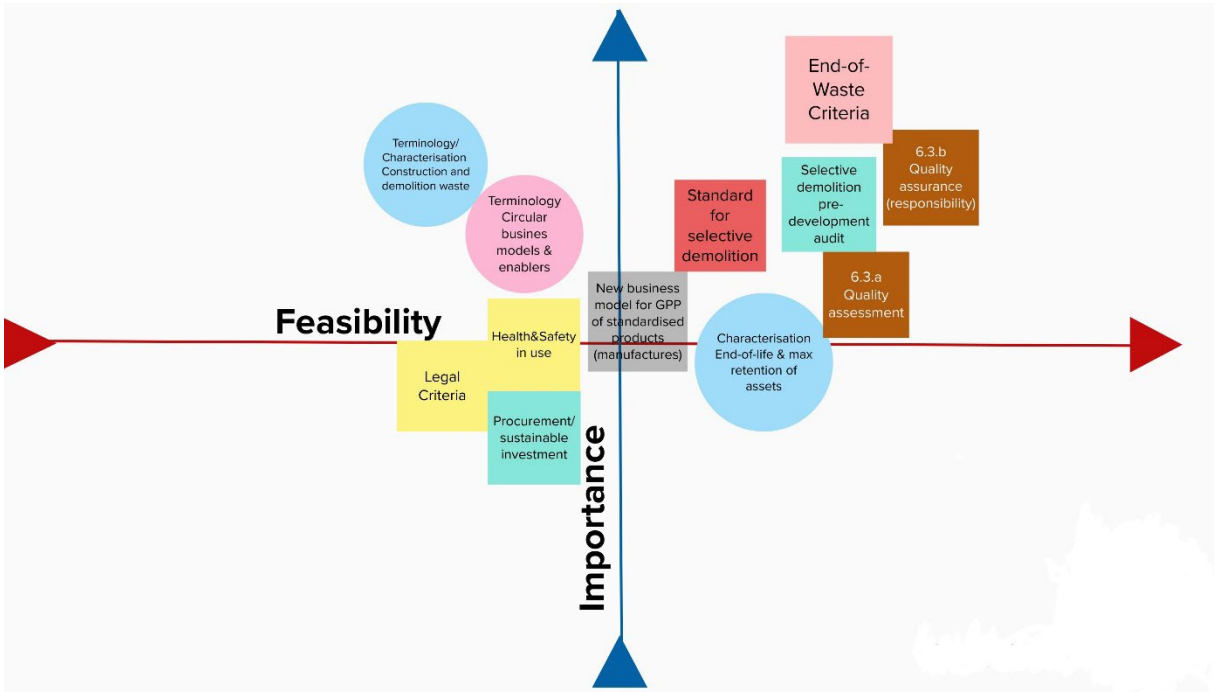

Figure 7 Based on the feasibility and importance of standardisation activities, identified priorities for quality assurance of reused and recycled material, end-of-waste criteria.

Understanding the end-of-life scenarios and maximizing asset retention is crucial. While the importance of this characterization was acknowledged, the experts recognized the challenges in managing it effectively. Defining the tipping point when waste becomes a resource is fundamental. The experts reiterated the importance of clear criteria. These guidelines drive sustainable practices and encourage resource efficiency. Pre-demolition audits are not just a technicality; they hold immense importance. Optimizing resource recovery requires strategic planning from the outset. The experts emphasized its role in minimizing waste streams. While still high priority, having consistent terminology matters. The experts recognized the importance of shared language. Clarity fosters collaboration and streamlines communication across stakeholders. Although the practical implementation of circular economy concepts remains distant, acknowledging their importance is

essential. These models challenge traditional linear thinking and pave the way for sustainable business practices.

Insights underscore the delicate balance between importance and feasibility. Bridging standardization gaps necessitates strategic planning, collaborative efforts, and a shared commitment to sustainable practices. As the construction industry evolves, these expert perspectives guide us toward a greener, more resilient future.

6 Design for circularity, adaptability and disassembly

Based on consultation with national member bodies, CEN/TC 350 performed an analysis that addressed, among others, gaps in planning and design (classification/definition, rules and methods for performance assessment, guidance and testing requirements for reused products and materials, framework for re-certification of materials and components, ease to deconstruct and reuse (connection type, weight, built on site of prefabricated), assessment methodology for existing buildings, design for change of function/use, execution of works, flows of materials from buildings, pre-demolition audits) and circular procurement (framework for technical procurement criteria, circular and green procurement, carbon footprint in procurement, country-specific circular procurement criteria, whole-life cost).

The registered participants identified the following standards and guidelines that are related to design for circularity and circular procurement:

1. ISO 20887: Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance (ISO 2020)
2. ÖNORM B 3151: Dismantling of buildings as a standard method for demolition (ÖNORM 2014)
3. CSA Z782-06: Guideline for design for disassembly and adaptability in buildings (CSA 2006)
4. A guide to circularity in construction (PLGBC 2023)
5. Guidelines for the deconstruction of existing buildings (Gambato 2022)
6. Circular purchasing - Guiding principles for circular construction (CB23 2021)
7. Circular design 2.0 - Working agreements for circular construction (CB23 2023)
8. Provisions for a greater reuse of steel structures (PROGRESS) project[2]

The standardisation gaps identified through the survey at the registration phase (Figure 8) relate to test methods for technical requirements (like detachability) that are reliable throughout the life cycle and beyond in the case of re-use, storage of refurbished constructions or construction elements, resilience, inspection before renovation and demolishing, integration of circularity and decarbonisation, insurance of buildings using reclaimed materials, and liability.

Additional gaps were harvested during the parallel session regarding i) materials (data and material history, source of materials, endurance and optimum use during the technical life, transparency on materials used in products), ii) planning and design (design for adaptability, modular construction, selective demolition, quality control, acceptance by consumers, harvesting by-products, avoiding release of hazardous materials, use of new technologies, balance reuse/recycling versus energy efficiency) and iii) training to acquire the needed skills and capacities.

As shown in Table 3, these gaps refer to various stages of the building life cycle (planning, end-of-life, beyond life cycle and design of new buildings). Most gaps are related to early phases of standardisation (terminology, definitions, and metrology) and some gaps to later phases (performance characterisation, compatibility).

[2] https://www.steelconstruct.com/eu-projects/progress.

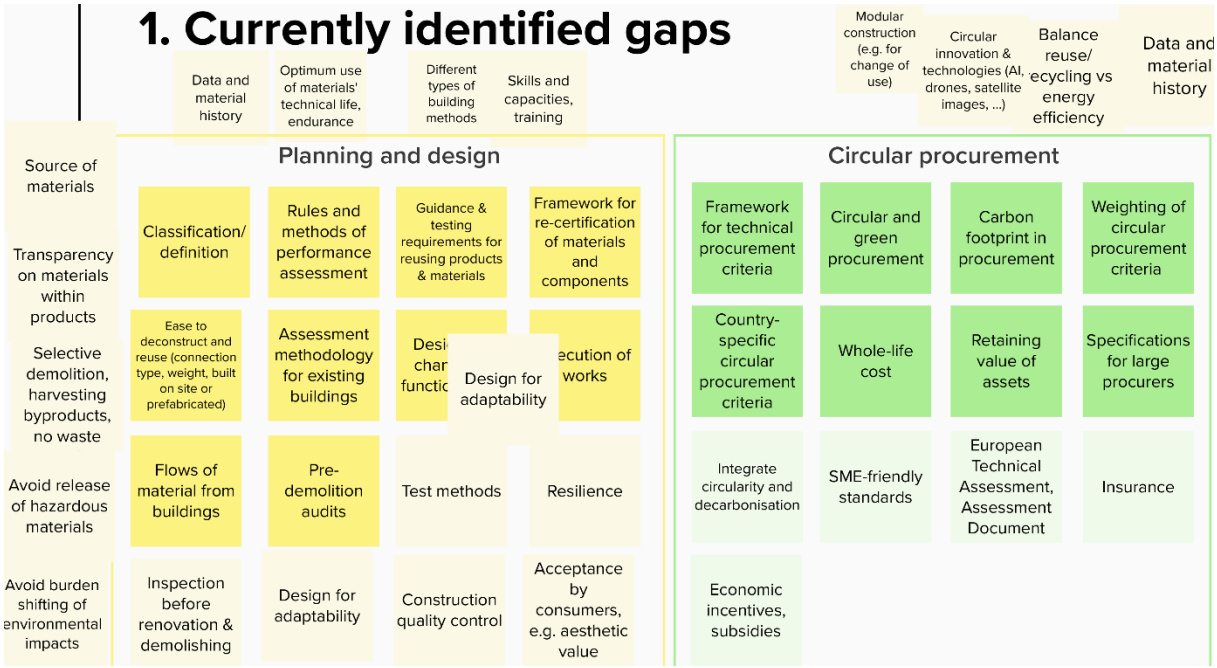

Figure 8 Identified gaps for design for circularity, adaptability and disassembly.

Design for circularity and circular procurement were both identified in the input provided at the registration phase as important as most of the other gaps in the analysis by CEN/TC 350. The most important aspect to improve regarding design is related to performance characterisation, whereas for circular procurement it is terminology. Relatively high effort is needed to develop standards for circular procurement. On the other hand, the responders indicated that it is relatively feasible to develop standards for design.

Table 3 Prioritised gaps for design for circularity and circular procurement shortlisted by the workshop participants in relation to the circular building life cycle a) use, b) planning (existing building), c) end-of-life, d) beyond building LC, e) product, f) design (new building), g) construction.

Operability assessment	1a	1b	1c	1d	1e	1f	1g
Compatibility (system integration)	2a	2b	2c	2d	2e	2f Design for change of function / use	2g
Performance characterisation	3a	3b Rules and methods of performance assessment	3c	3d	3e Ease to deconstruct and reuse (connection type, weight, built on site or prefabricated)	3f	3g
Metrology (indicators)	4a	4b Carbon footprint in procurement	4c Pre-demolition audits Assessment methodology for existing buildings	4d	4e	4f	4g
Terminology & definitions	5a	5b Classification/definition	5c End-of-waste criteria (legislation) Testing requirements for reusing products & materials Retaining asset value	5d Framework for re-certification of materials and components	5e	5f	5g

Figure 9 illustrates the assessment of the feasibility to address several important standardisation gaps related to design for circularity and circular procurement, as discussed during the parallel session. In detail, the development of standards on the use of new technologies (e.g., A.I., drones, satellite images) for circular construction is deemed the most difficult. On the other side, there are several aspects of equal importance that are easy to develop (e.g., framework for re-certification of materials and components, guidelines and testing requirements for reusing products and materials, end-of-waste criteria). The design for change of function/use as well as data and material history are of the highest importance. Although not really a standardisation need, training for skills and capacities is rated as important and quite feasible to develop.

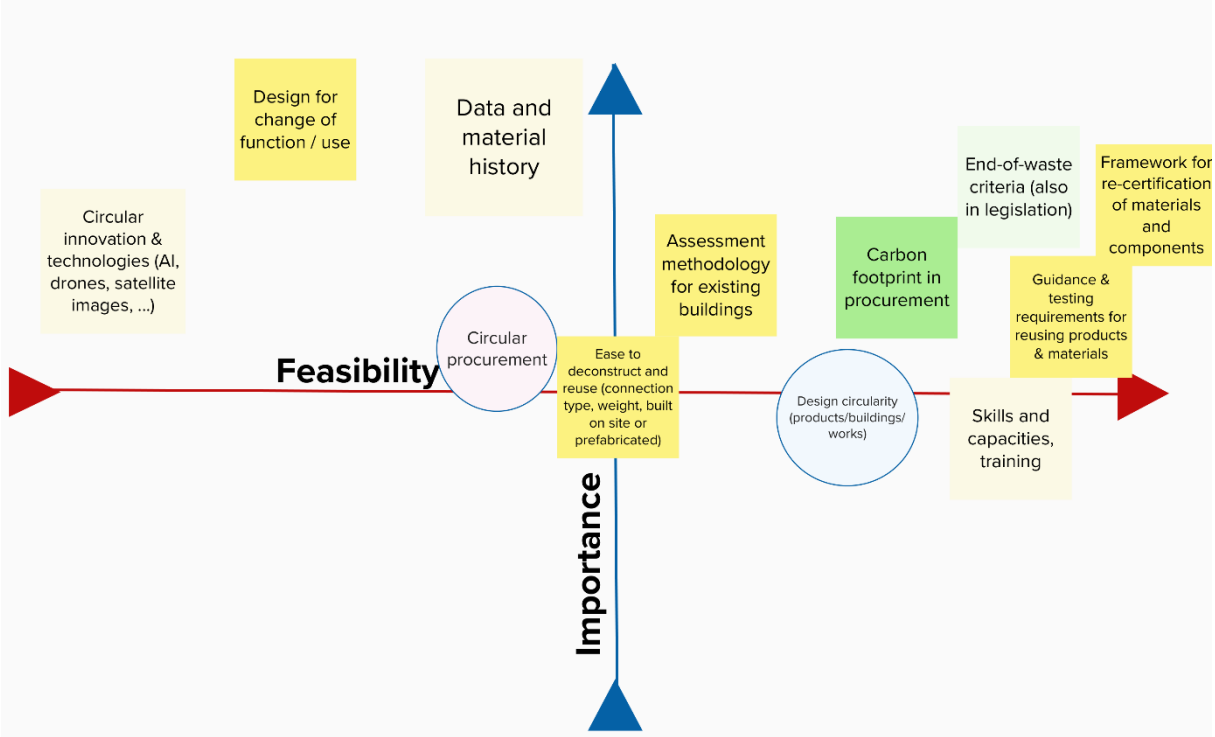

Figure 9 Based on the feasibility and importance of standardisation activities, identified prioritised design circularity (i.e. products, building, works) and circular procurement.

Figure 10 presents in the form of a word cloud the top actions recommended by the participants of the parallel session to support embedding circularity, adaptability and disassembly in design. The most popular recommendations refer to performance criteria, assessment method and clear definitions.

Figure 10 Top actions in standards which will support embedding circularity, adaptability and disassembly in design.

Drawing insights from the survey responses of 411 workshop participants, we find that addressing standardization gaps in circular procurement is of paramount importance (as indicated in Figure 9). However, the feasibility of overcoming these gaps hinges on various contextual factors, which may see resolution within a medium timeframe. Additionally, while less critical, the need for circularity designs in products, buildings, and works is anticipated to be addressed soon.

In Figure 9 survey data gathered from 30 experts provide insights into priorities of tackling standardization gaps across the domain of this session. The findings suggest that several areas are both prepared and important to tackle standardisation challenges. These include the development of frameworks for re-certification of materials and components, establishment of guidance and testing requirements for product and material reuse, and formulation of end-of-waste criteria, particularly within legislative frameworks. Additionally, there is recognition of the importance of standardisation in enhancing skills and capacities through training initiatives and in managing carbon footprints in procurement processes. Moreover, experts emphasize the critical importance of addressing standardization gaps in several key areas, including designing for change of function or use, tracking data and material history, advancing circular innovation and technologies such as AI, drones, and satellite images, implementing assessment methodologies for existing buildings, and reinforcing frameworks for material and component re-certification.

7 Building information (reporting formats, data management and storage)

Platform CB'23 - Passports for Construction: Platform CB'23 aims to stimulate the transition to a circular construction economy. Their guide on Passports for the Construction Sector provides a methodology for assessing the sustainability of building products. Passports can be applied across the buildings and construction sector, benefiting various stakeholders, including clients and contractors. The standard practice for data collection for sustainability assessment of building products, an ASTM standard (E2129-18), outlines instructions for collecting data to assess the sustainability of building products. It helps inform decisions related to construction, renovation, repair, and maintenance, promoting sustainability and sustainable development. The practice covers aspects such as material selection, manufacturing processes, operational performance, and environmental impact.

ISO/DIS 59040 provides a general methodology for improving the accuracy and completeness of circular economy-related information. It focuses on using a Product Circularity Data Sheet during product acquisition or supply. The guidance covers data format, content, and sharing, aiming for cross-sectoral applicability and confidentiality protection. JTC 24 is involved in the development of deliverables related to the Digital Product Passport (DPP) framework and system. This includes standards for unique identifiers, data carriers, access rights management, data exchange protocols, and more. The goal is to enhance cross-sectoral and cross-system interoperability.

While specific standards are not mentioned, the Digital Deconstruction project explores innovative approaches to deconstructing buildings using digital methods for efficiency and sustainability. The 100 Gruppen project encompassing standardized digital product templates supported by REXS platform aims to create standardized digital templates for inventory, handling, and data exchange of reusable and new building parts, products, and furniture. These templates facilitate consistent data management and interoperability across the industry.

In the domain of building information, which includes reporting formats, data management, and storage, there are several standardisation gaps. The Declaration of Performance (DoP) which has been introduced by the Construction Products Regulation (305/2011/EU) does include circularity, but it's not comprehensive and misses requirements, such as specific indices and metrics. However, the current work on new requests for standardisation for construction products covered under the CPR are referring to the characteristics and indicators in EN 15804. The current approach is still predominantly cradle-to-grave, with limited focus on circularity. A gap between the information provided at product level and the information needs of users (e.g. architects, designers, contractors and building control authorities) has been identified: In general, there are legal aspects, like long-term reliability of data and data security and technical aspects like the format and content of the digital product passport and the digital building passport which need more standardisation to ensure traceability and transparency.

The development of a standardised data framework is ongoing, with the aim of improving data management and storage. Key Performance Indicators for circularity are not yet standardised across the industry. Technical requirements and test methods for detachability, a key aspect of circularity, are not yet fully standardised for information systems. Although not falling under the remit of TC350, but instead under CPR, there is a need for standardised security measures to prevent fraud in the reporting and management of building information. These gaps highlight the need for ongoing efforts to develop and implement comprehensive and effective standards in the domain of building information.

Table 4 Prioritised gaps building information (reporting formats, data management and storage) shortlisted by the workshop participants in relation to the circular building life cycle a) use, b) planning (existing building), c) end-of-life, d) beyond building LC, e) product, f) design (new building), g) construction.

Operability assessment	1a	1b	1c	1d	1e	1f	1g
Compatibility (system integration)	2a	2b	2c	2d	2e Digital product passport	2f	2g
Performance characterisation	3a	3b	3c	3d	3e Digital product passport	3f Detachability for circularity technical req, test methods, for Information system	3g
Metrology (indicators)	4a	4b	4c	4d	4e	4f Declaration of performance including circularity	4g
Terminology & definitions	5a	5b	5c	5d Category rules	5e	5f Requirement for circular design and use	5g

A significant gap exists in the integration of Digital Twins and Building Information Modeling (BIM), both crucial tools in the construction industry.Open semantic interoperability between standards is lacking, necessitating global standards infrastructures. Bridging this gap through a standard would enhance the smooth integration of data from Digital Twins and BIM, boosting efficiency in building design, construction, and performance.

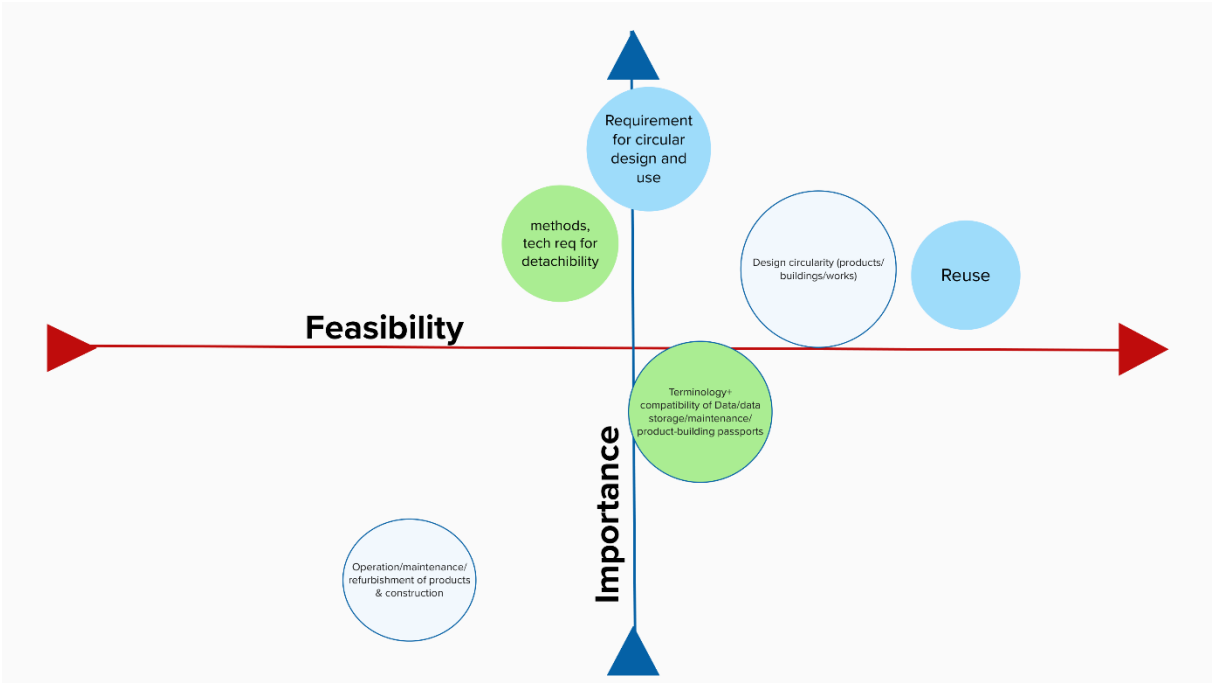

Figure 11 Based on the feasibility and importance of standardisation activities, identified priorities for building information (reporting formats, data management and storage).

Another critical area requiring standardization is digital building logbooks and data interoperability frameworks. The current challenge lies in managing scattered data resources across various

stakeholders. Standardizing data collection, management, and interoperability is essential to overcome information silos.

The survey data from 30 experts provides a comprehensive assessment of the readiness level and the importance of addressing standardisation gaps in various areas (Figure 11). The experts indicate a feasible and ready approach to tackle standardisation in areas such as reuse, design circularity (products/buildings/works), and terminology, compatibility of data, data storage, maintenance, and product-building passports. These areas are deemed ready for standardisation, indicating a positive trend towards sustainable practices.

On the other hand, the importance of tackling standardisation is highlighted in the requirements for circular design and use methods, and the technical requirements for detachability in design circularity (products/buildings/works). These areas are seen as crucial in the transition towards a circular economy, underlining the need for standardisation.

A larger survey involving 411 participants revealed a contrasting perspective in the domain of Building Information. While design circularity (products/buildings/works) was recognised as important and relatively convenient to handle in a short time horizon, the standardisation gap in the operation, maintenance, and refurbishment of products & construction is far from being ready to tackle any time soon. This indicates a significant challenge that needs to be addressed to ensure the successful implementation of circular economy principles in the building sector.

8 The way ahead

In summary, this workshop identified key areas for CEN/TC 350. The report highlights specific areas that CEN/TC 350 may consider in their future work programme and suggests high priority topics based on discussions with stakeholders. During the prioritisation exercise, the importance of having clear objectives and focused standards was emphasized. CEN/TC 350 strives to create horizontal standards that provide the greatest added value. The workshop identified additional important topics. The first topic pertains to cost, which is crucial in identifying cost-effective solutions and promoting uptake. Furthermore, it is imperative to establish common future scenarios and a practical pathway for reuse. The establishment of a resource indicator to determine the significance of resources, including critical raw materials, and how to manage them is another important topic. In order to position CEN as a gateway for manufacturers who are interested in circularity, it is important to address the practical aspects of implementation. When developing standards, it is crucial to consider how we can promote progress in the market and create standards that facilitate decision-making processes, with a focus on identifying cost-effective methods for reuse.

The workshop topics are also relevant to the European Commission's Annual Union Work Programme on Standardisation (AUWP), which outlines its priorities for standardisation-related activities. The AUWP currently covers certain aspects of circular construction, such as decarbonisation, low-carbon cement, and green steel. However, it is important to address the entire supply chain, rather than solely focusing on material reuse. The European Commission has established the High-Level Construction Forum, which complements the AUWP by identifying the necessity for standards, distributing them to relevant services and departments, and providing tangible examples for standardisation. The responsibility of organising standardisation lies with DG GROW. Currently, GROW is considering the utilization of the Horizon Europe programme to aid in standardisation efforts. The primary aim is to determine the standards requirements and how research and standard-setters can work together to meet these future needs.

Most of the construction sector is made up of SMEs, and therefore it is important to keep in mind how SMEs will face the challenge of having to meet the same standards as the big industries, and whether the requirements set will be too expensive to meet. To be able to continue this work, the standards put forward need to consist of an understandable framework, which is SME-friendly. A large part of the construction industry is made up of small companies, with limited financial and time resources. If we want the standards to be a useful tool to support the transition towards circularity, they need to be practical and accessible to SMEs, which unfortunately is not the case today. Some steps towards more accessible standards include making cost efficient solutions, broadening market acceptance, focusing on interoperability, and ensuring qualified people to meet the digital and environmental ambition.

Manufacturers are another important stakeholder community. The current housing crisis, demands the need for affordable, suitable, and sustainable housing all at the same time. In order to transit to circular construction, it may be necessary to establish end-of-waste criteria. It is worth noting that these criteria are not currently mentioned in the Annual Union Work Programme. Furthermore, it is important to maintain product and technology neutrality, which would allow for flexibility in selecting the appropriate solution and ensuring that the entire life cycle is considered. The workshop identified some potential solutions for transitioning towards a circular construction sector. However, there are still some unresolved aspects that may require further legislation, standards, and collaboration. It is important that we work together to address these challenges in a timely and effective manner.

The New European Bauhaus initiative focuses on accelerating the European Green Deal can help shape a circular construction ecosystem. Ongoing work aims at developing a new instrument to fund research related to circular construction, reuse of materials including pre-normative research.

It is important to keep in mind the view of the consumers. There seems to be a general lack of trust in the performance and quality of reused materials from the consumers. This should be turned around, so the consumers see reused and virgin materials with the same eyes. There was a general agreement from our panellists, that the way to satisfy the clients and investors regarding the reliability of reused materials is to test and declare their performance.

The work accomplished in this workshop, especially the prioritisation exercise will be very useful to feed into the work done by CEN/TC 350. The views shared at this workshop both during the plenary sessions and the discussions in the breakout rooms have given a good overview of the future needs for standardisation within circular construction and given a good base for moving into more specific discussions.

9 Conclusions

The Putting Science Into Standards Workshop (PSIS) initiative aims to identify emerging science and technology areas that could benefit from standardisation activities, enabling innovation and enhancing industrial competitiveness. Each year the collaborating partners JRC and CEN and CENELEC select a topic for a PSIS Workshop from a variety of proposals made by JRC scientists.

The 2023 workshop on circular construction addressed the current and future needs of the construction sector and recommended ways to support a cradle-to-cradle approach that aims to minimize waste by creating a closed-loop system. The workshop was intended to enhance the relationship between the standardisation community and policymakers.

The workshop was attended by nearly 412 experts from 27 Europe countries, 11 EU neighbourhood countries and 14 overseas countries, representing researchers, innovators, regulators, standardisation specialists and end users from industry. Amongst the participants there were delegates from ISO, the National Institute of Standards (NIST), the American Society for Testing and Materials (ASTM) and American Society of Civil Engineers.

The event was supported by DG GROW and the New European Bauhaus and was based on the RTD's industrial technology roadmap for circular technologies in the European Research Area. The roadmap identified technologies and standardisation gaps that need to be addressed in the European framework programme for research, contributing to the development of the industrial ecosystems highlighted in the European Industrial Strategy. The workshop was informed by the gap analysis recently completed by the technical committee 'Circular Economy in the Construction Sector' (CEN/TC 350/SC 1), which identified 9 gaps.

Construction is a significant topic within standardisation. This workshop provided an opportunity for a new branch of standards to emerge towards circular construction. In dedicated sessions, discussions generated a lot of new material, highlighting the needs and identifying next steps. The workshop explored the significance of ensuring safety and trust in construction materials, as well as the recycling ability and performance of building materials. It also emphasized the importance of staying up to date with the use of materials, revising quality standards, establishing end-of-waste criteria, and reviewing terms such as reuse versus repurpose. When developing standards, it is important to consider the perspective of the consumer. Quality and environmental impact should be addressed, not just cost. The workshop successfully took these topics into consideration. Productive conversations have been held regarding the requirements and possibilities in this developing field, where standards can aid in finding solutions.

The workshop put forward the following recommendations for next steps:

- CEN/TC 350/SC 1 had a pivotal role in the organization of this workshop and the outcomes of these two days of discussions should feed in the work programme of the subcommittee with concrete recommendations in terms of future standards to be developed.
- This work should be well anchored within policy initiatives promoted by the European Commission and should build on the work done by other technical committees that are developing horizontal framework to support a circular economy transition such as ISO/TC 323 (Circular economy).

— Future work should exploit the collective European strength in ISO and IEC. CEN and CENELEC Members are represented in ISO and IEC and also seize opportunities to work with like-minded international partners to bring the European ambitions for a green transition at the international level.

— Moreover, input from these two days of discussion can also feed into European Commission initiatives, for example providing input for the development of the future Annual Union Work Programme for European Standardisation and for future calls addressing pre-normative research needs into EU research and innovation funding programmes.

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AI	artificial intelligence
ASTM	American Society for Testing and Materials
AUWP	Annual Union Work Programme
BAMB	Buildings as material banks
BIM	Building information modelling
CDW	Construction and demolition waste
CE	Circular economy
CEN	European Committee for Standardisation
CENELEC	European Committee for Electrotechnical Standardisation
CPR	Construction products regulation
DG GROW	Directorate General for Internal Market, Industry, Entrepreneurship and SMEs
DG RTD	Directorate-General for Research and Innovation
DPP	Digital product passport
EN	European norm or European standard
EPD	Environmental product declarations
ERA	European Research Area
ISO	International Standardization Organization
JRC	Joint Research Centre
LC	Life cycle
LCA	Life cycle assessment
PSIS	Putting Science Into Standards initiative
SC	Subcommittee
SME	Small and medium sized enterprises
TC	Technical committee
TRL	Technology readiness level

Annexes

Annex 1. Selected standardisation and harmonisation approaches for circular construction

Platform	Topic
ASTM - e2432-23	General principles of sustainability relative to the built environment.
ASTM - e2921-22	Minimum criteria for comparing whole building life cycle assessments for use with building codes, standards, and rating systems.
ASTM Post-Event Report	Fostering a Circular Economy of Manufacturing Materials Workshop Report 2022
Chartered institution of building services engineers (CIBSE)	Circular economy principles for building services.
Ellen MacArthur Foundation.	Circular buildings toolkit takes principles of the CE and translated them into a prioritised set of actions relevant for the built sector. Alongside circular building guidance are real-life examples.
CEN EN15978	Sustainability of construction works specifies the LCA calculation method to assess the environmental performance of a building and gives the means for the reporting and communication of the outcome of the assessment.
Facilitating the Circulation of Reclaimed Building Elements (FCRBE)	Facilitating the circulation of reclaimed building éléments. L'assurance et le reemploi enseignements des etudes de cas et perspectives.
Futurebuilt	Criteria for circular buildings in Norway
ISO FDIS 59004	Circular economy — vocabulary, principles and guidance for implementation.
ISO FDIS 59020	Circular economy — measuring and assessing circularity performance.
Norden.	Nordic networks for circular construction and nordic sustainable construction.
North West Europe	Set, monitor and report on reclamation and reuse rates in construction projects a common approach.
Planon	Building circularity indicator using smart sustainable building management software.
Platform CB'23.	Measuring circularity current measurement method can be used for gaining an understanding of the degree of circularity of a structure.
Polish green building council.	A guide to circularity in construction and how to apply the CE principles in construction based on design in accordance with the CE idea.
UK Green Building Council.	Circular economy metrics for buildings.
World business council for sustainable development 2022.	Measuring circular buildings – key considerations.
World green building council 2023.	The circular built environment playbook, available

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