encord

CIRCULAR ECONOMY REPORT

Towards A New Thinking on Construction Project Delivery

How to accelerate circularity in the Construction Ecosystem

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01. Executive Summary

A few fundamental ways exist to increase the circularity of buildings and construction materials. For new construction, it is imperative to apply material substitution and design for flexibility while minimizing waste. Material substitution is used to increase the use of bio-based, recycled and reused materials. Flexibility in design covers a wide range of somewhat intertwined design methods aiming at increasing the adaptability of a building and/or ease of disassembly. Over time, the functional requirements of a building may change.

To ensure a building provides a relevant use, modifying the building becomes necessary. Making this modification easier by incorporating the capacity to change the building layout is the goal of design for adaptability. This can be achieved by separating building elements, using interchangeable components, oversizing building elements and through designing for disassembly. While designing for disassembly can be used to increase the adaptability of a building, it is also used to allow for the reuse and recycling of building components and materials.

However, the most significant challenge for circular construction lies with the existing building stock. Extending the service life of existing assets through renovation, maintenance and disassembly will be crucial moving forward.

To achieve a circular industry, construction needs to modify how built assets are designed and constructed, but also work to reform the way the industry is structured: the types of companies involved in the project delivery, the types of contacts and transactions between parties and the underlying business models. Successfully implementing circular construction practices requires skilled orchestration of a vast and loosely coupled ecosystem. Bringing together design for deconstruction, temporary joinery techniques, optimized material use across the life cycle of assets and material recovery routes in cooperation with numerous stakeholders will be key.

A transition towards a circular construction industry is already underway. The demand for circular designed and built assets from public and private investors will only increase.
For existing firms, “the way things are done”, traditional behaviours, customs, and prevailing orthodoxies, need to be disrupted. Innovation comes in different shapes, and circularity is just another form of innovation. With more data available, new business strategies and new ecosystems, circularity in construction might not be a challenge as insurmountable as it seems.

To achieve a circular construction industry, there is a need to shift focus:

- From new construction to preserving the value and increasing utilization of existing assets.
- From using virgin materials to incorporating reused, recycled and bio-based materials.
- From static to circular design principles that create and retains value over the life cycle of assets.
- From linear value chains to value creation and delivery through collaboration from across a network of actors.

02. Foreword

ENCORD is a forum, inviting its members to exchange openly on topics and issues of research, development and innovation of the built environment. Whilst most members are – as the name ENCORD suggests – contractors, all members are very aware that the prevailing challenges such as climate change mitigation and adaptation, with its main focal action fields, CO2-neutrality, efficiency of non-renewable primary materials, protection of biodiversity cannot be tackled if we stick to our traditional way of conducting project-oriented business. That is why we appreciate the engagement of major players in the construction supply chain within our association.

Based on previous work within ENCORD, we decided to devote our time to the highly relevant topic of circular construction. We were honoured by highly acknowledged guest speakers, such as Carol Lemons from ARUP, Tom Blankendaal from Royal BAM Group, Jad Oseyran from WiseBrick, Caroline Stern from Hilti, Anja Rosen from the University of Wuppertal and Dominik Campanella from Concular, who dedicated their valuable time and shared their insights and great xamples on how circularity can be enabled in the construction sector. We would like to especially honour the efforts of Magnus Österbring from NCC, compiling this report as the leader of the sustainability working group. Furthermore, we would like to recognize Norbert Pralle's long standing engagement as ENCORD's chair and his drive in initiating this report as well as many other cooperative undertakings for the advancements of the construction sector. Special thanks also go to Dominik Mann from STRABAG, Christina Claeson-Jonsson from NCC, Olivier Lépinoy from Autodesk, Edith Guedella Bustamante from Acciona, and Stephanie Whittaker from BAM for their valuable contributions and revisions of the report. Moreover, we would like to express our gratitude to Antonio Burgueño from FCC, Ilari Aho from Uponor, Edith Guedella Bustamante from Acciona, Peter Reisinger from Doka, Geert van der Linde from Ballast Nedam and Magnus Österbring from NCC for the provided case studies that enrich the report with practical examples. Finally, special thanks go to all ENCORD working group leaders and the dedicated members driving advancements in their respective fields across the construction sector.

This report does not aim to give a general overview of the great work that is abundantly available on circularity in the built environment, particularly from academic institutions.
This report aims to shed light on the challenges and success factors identified by ENCORD members from across Europe to share solutions and highlight pathways for a circular transition in the construction industry. There are examples emerging from across Europe on how many of these opportunities are seized using new business models, data-driven approaches and utilising digital platforms to disrupt the industry, as well as practical examples of reuse, renovation and applying bio-based materials showcased throughout the report.

This report is the result of a concerted effort by the Council and the five working groups of ENCORD, Foresighting, Sustainability, Digital Built Environment, Lean and Health & Safety during the time period March 2020 to March 2023.
We would like to thank all our members for participating actively in ENCORD's working groups. Finally, we would like to thank all the council members and representatives that support the collaboration within ENCORD.

„Anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist.“

Kenneth Boulding, 1973

03. Introduction

Kenneth Boulding's shocking truth summarises the report "The Limits to Growth" published by the Club of Rome in 1972 *[1]*. The earth's limited resource base sets irrefutable boundaries to population growth and economic development - yet an ever-faster number of humans demands nourishment, housing and infrastructure as well as mobility. In the decades to come, Europe's built environment must provide housing and infrastructure for more people with a limited amount of readily available virgin resources.

The EU's green deal, including initiatives such as the taxonomy of sustainable finance *[2]*, the circular economy action plan *[3]*, the renovation wave *[4]* or the Fit for 55 package *[5]* emphasise the sustainability focus of political and subsequent legislative streams. Since the construction sector accounts for 8.2% of the GDP and almost 10% of total employment *[6]* within the European Union, the green transition does not only provide challenges but also ample opportunities for economic and social development.

The EU's current building stock consumes approximately 40% of the total energy and account for 36% of CO2 emissions in the EU. Since more than 35% of buildings in the EU are older than 50 years and considered energy inefficient *[7]*, many of them will have to be renovated or rebuilt in the coming years.

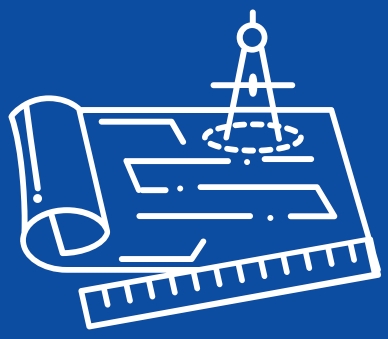
Taking advantage of the existing building stock and infrastructure via refurbishment, reusing, repurposing as well as recycling of building materials offers an opportunity to tackle several challenges at once. Next to providing a reliable source of construction material, reused and refurbished materials have the potential to reduce the sector's carbon footprint substantially. However, closing the material-loop and thus enabling a circular construction industry requires unprecedented collaboration amongst all stakeholders in the built environment.

ENCORD and its members from up- and downstream of the construction value chain are uniquely situated to provide a platform and cutting-edge expertise for solving parts of the challenging circularity puzzle.

As Europe's leading contractors and suppliers of the built environment, we want to answer the call for a new perspective on the life cycle of materials, buildings and infrastructure and the innovative business models that enable a circular, prosperous construction industry.

03.01.

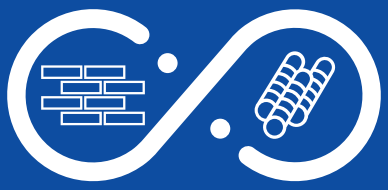
Circular economy principles



Design out waste[1]

The design of materials and products is shaped by their functions and purpose as well as aesthetic appeal. However, design is also a key factor of how much value of a product can be recovered at the end of its life. Subsequently, material and product design influence how much material is fed-back in the material loop and what amount go to landfills. By asking the crucial question of "what happens to this at the end of its life", it draws attention to opportunities inherent in maintaining, sharing, reusing, repairing, refurbishing, remanufacturing or recycling a product. Improving designs provides a pathway to reducing and even eliminating waste in economies.

[1] The Ellen MacArthur foundation defined circular economy as "restorative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" (EMF, 2015).



Circulate products and materials

Keeping materials and products in use as long as possible at the highest value is another core principle of a circular economy. Prolonging products' lifespan by maintaining or refurbishing allows for the highest retention of value. At the same time, repurposing or remanufacturing individual components maintains a high degree of material value. Finally, down-/recycling of products, components and materials allows often only for a limited amount of value retention. The value retention opportunities rely on the technical or biological nature of products and materials.

Regenerating Nature

At the heart of a transition from the take-make-waste linear economy to a circular economy is the minimal use of virgin materials. Shifting from continuously extracting materials to gradually building up of material capital enable a regeneration of resilient natural systems capable of coping with changing climate conditions.

ZERO WASTE

CD3 – CD4 TORIJA CAMPUS
Contractor: FCC Industrial
Property Owner: SILC IMMOBLES, S.A.

Project Information

As it's well known, construction sector has traditionally been characterised by the high volume and heterogeneity of the waste generated. FCC Construcción, aware of the importance of a good waste management and the need to go one step further to reduce its impact on the environment, has achieved, through its subsidiary FCC Industrial, the "Zero Waste" traceability system certification (granted by AENOR) in the project "CD3–CD4 Torija Campus".
As a result, FCC Construction was the first construction company to achieve this certification. Implementing "Zero Waste" means that at least 90% of the waste generated by the site is recovered and diverted from landfills. The implementation of this initiative was highly successful and the 99,99% of the waste generated by the work was recycled or reused.

Learnings

Achieving "Zero Waste" certification has not only brought environmental, economic and social benefits, but also the recovery of each fraction of waste generated, which is an even greater challenge for a construction company. Recovering more than 90% of the waste generated by the site is entirely feasible and at not additional cost. The success factors in this case have been the implementation of an internal waste management monitoring system and the intensive training provided to employees and, also, to subcontractors. The recovery of certain waste materials proved to be more challenging, in particular, waste which is not strictly construction waste, such as municipal waste, packaging waste, etc.

03.02.

Construction Status Quo – A Linear Value Chain?

As a consumer of 50% of all extracted materials, producer of 35% of total waste and source of up to 36% of total greenhouse gas emissions in the EU, the construction sector is considered a key value chain for the green transition. Measures like the Waste Framework Directive *[8]*, guidelines for waste audits *[9]*, outlining opportunities *[10]* and even proposing business models for construction and demolition waste recycling *[11]* have been undertaken to level-up the recovery rates across the European Union to the set-out target of 70% by 2020. Although individual member states are lagging behind, an average of 83% recovery rate of mineral waste across the EU countries was already achieved in 2018 *[12]*.

However, construction and demolition waste are often downcycled for backfilling or road sub-bases with limited value retention *[4]*. This can be attributed to building practices of the past that prevent the recovery and (re) certification of high-purity material as well as limited time, skills and established processes for high-quality disassembly. Meanwhile, the availability and easy access to low-cost virgin materials has hampered the emergence of functional and economical circular design and material solutions *[1]*. Aside from rare examples like dry-stack bricks *[5]*, construction materials and design processes have remained firmly rooted in a linear take-make-use-dispose model.

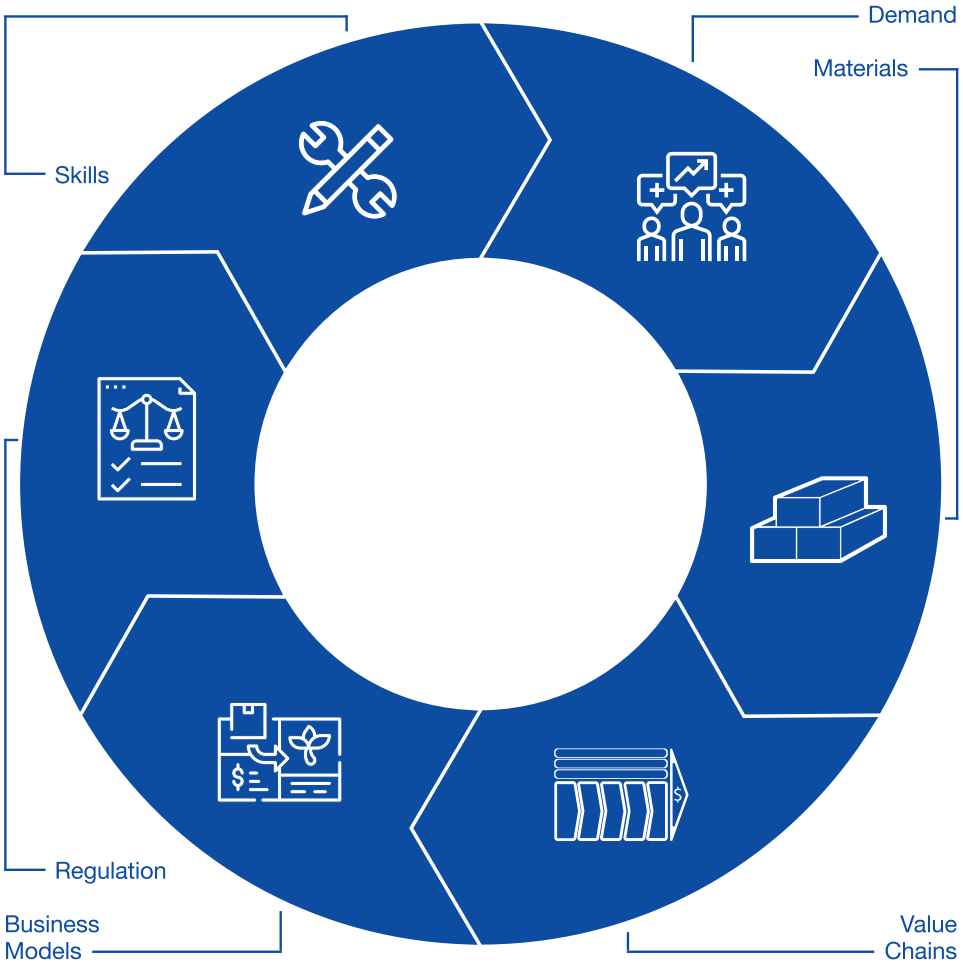
In contrast to readily available virgin materials, the widespread use of recovered materials has been inhibited by the absence of functioning market mechanisms coordinating available quantities, qualities and prices of salvaged materials. As a result of the ambiguous business case, investors, material manufacturers, architects and designers as well as general contractors have yet to be properly incentivised to apply design for circularity principles and consider end-of-life scenarios for buildings and infrastructure, henceforth referred to as assets. Preserving the inherent value of construction materials and products requires novel product designs, assembly and built approaches, recovery routes and contractual models that allow flexible ownership arrangements.

Despite the substantial financial, environmental and social potential of a circular construction industry, wide-spread recovery practices, re-certification schemes and viable business models remain largely absent.

A survey conducted amongst the ENCORD member representatives sheds light on the challenges and obstacles encountered when applying circular economy principles in the built environment. Six action fields emerged that require collaborative research and innovation across ecosystem partners to advance circular solutions in the built environment.

Life Cycle

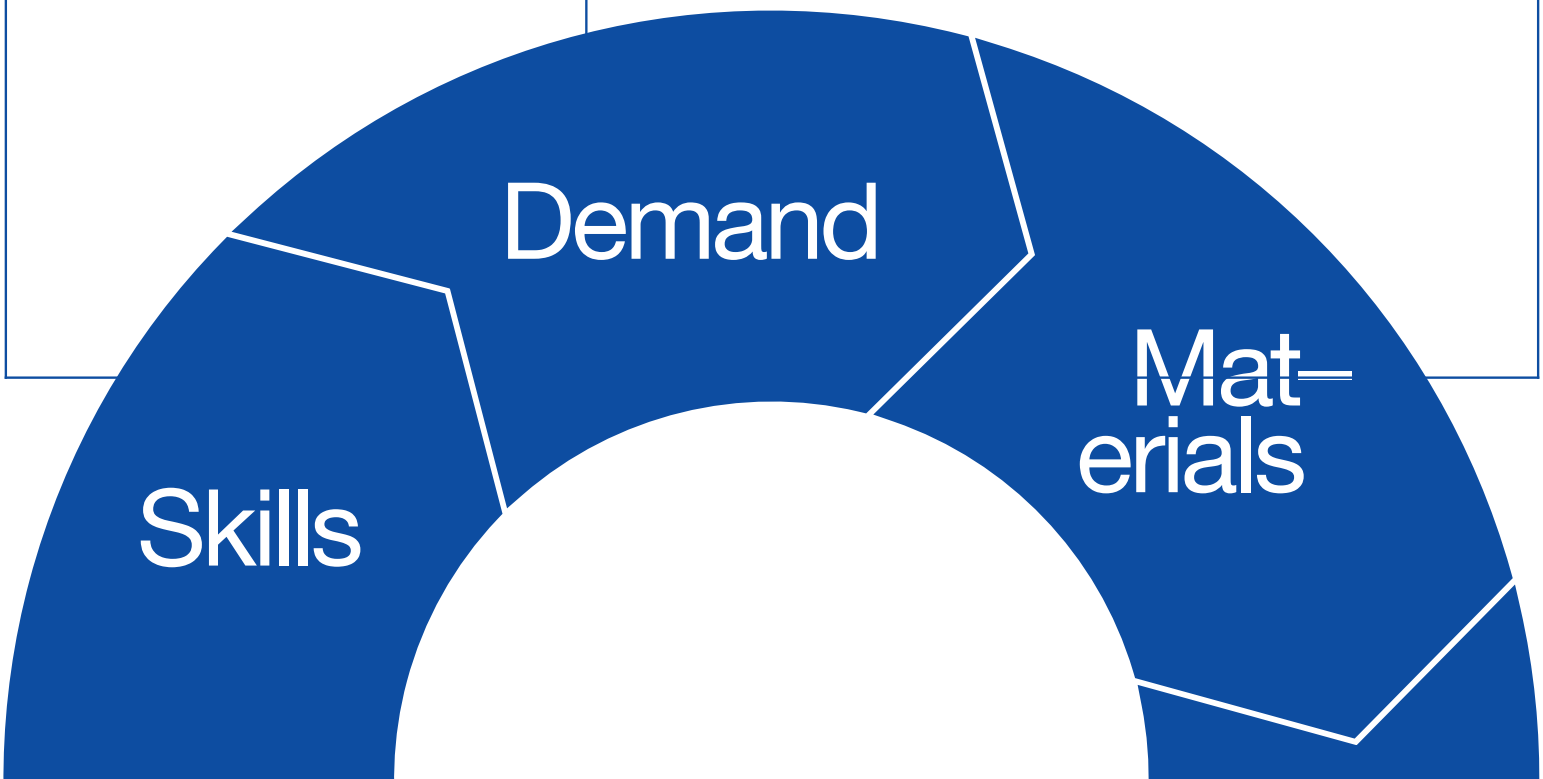
The life-cycle perspective is a key enabler at the heart of the circular economy. Conducting a life-cycle analysis (LCA) in the built environment requires considerations at the ***(a)*** material, ***(b)*** asset and ***(c)*** regional level. The diverging nature and service lives of these three aggregation levels result in ambiguity regarding the appropriate start- and endpoint of a LCA. Providing answers to what elements to consider, for how long and what economic and ecological costs can be attributed to reuse-, refurbishment or recycling rates is paramount for advancing LCA in the built environment ***[13]***. As often evident in the LCA of construction material, the environmental impact is largely dependent on the service life of components, potential future recycling rates and the number of service life cycles ***[14]***. Next to methodological advancements and supporting information technology, decision-makers and stakeholders in the built environment need to assist in the interpretation of LCA results in the circular economy setting.

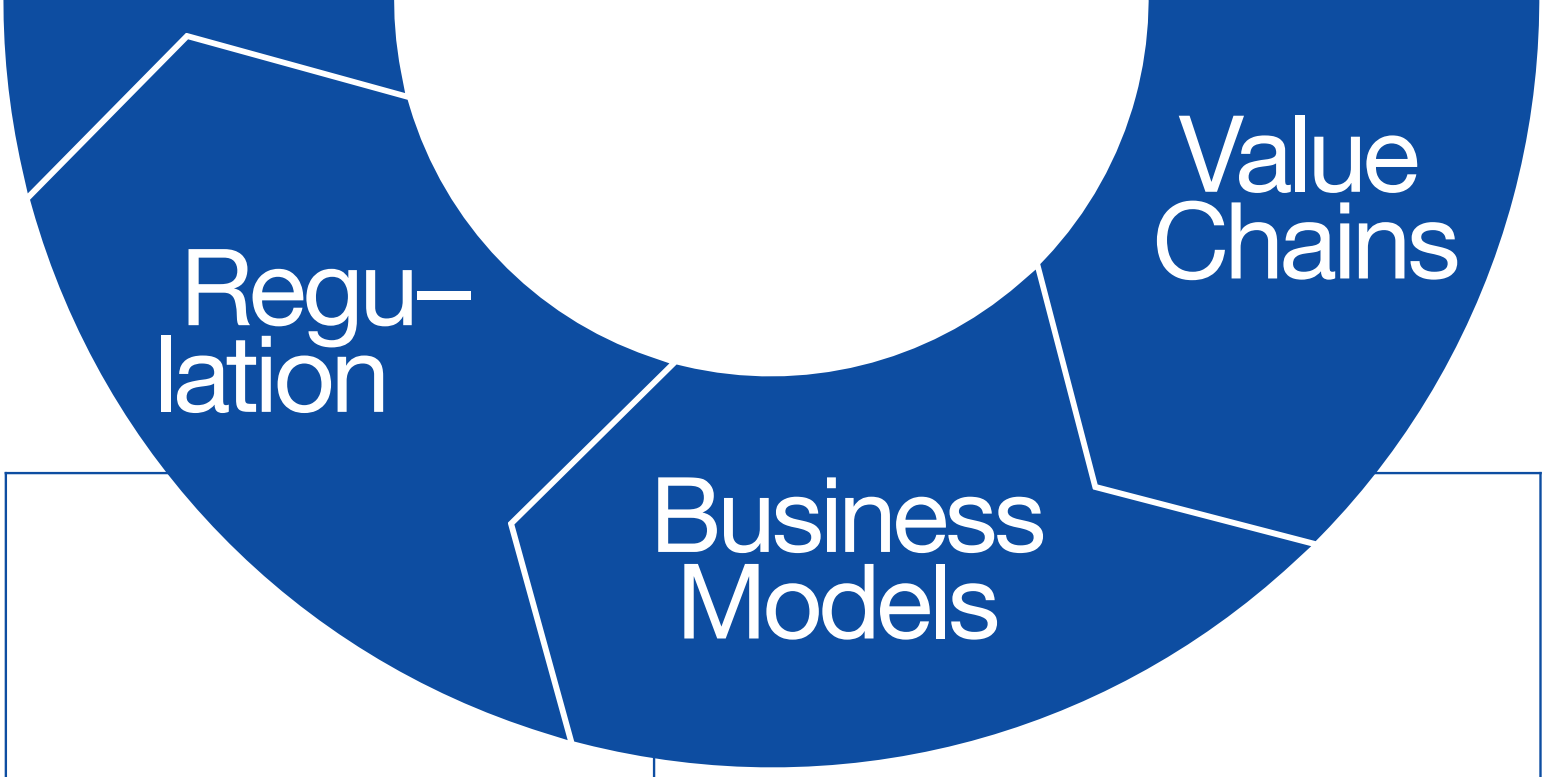


A circular built environment mandates a whole new set of skills and competencies. While design for disassembly is well-understood in theory, applying it to the planning of new and renovation of old buildings and infrastructure is a capability to be built by most contractors. At the same time, sourcing and purchasing circular material and installation services requires new modes of coordination. Additionally, designing building material for assembly and disassembly requires a new set of skills from material manufacturers as well as construction workers. Moving forward, skills relating to the maintenance, repair and refurbishment of the existing infrastructure and building stock will become increasingly important. Finally, material manufacturers need to develop innovative ways to refurbish, reuse and recycle building materials and products.

Public and private clients are incentivised by the EU taxonomy on sustainable activities to invest in sustainable assets. The increasing importance of certification schemes such as LEED, BREEM and Level(s) provide evidence for changing tides in the built environment. However, demand for secondary building materials at the industrial scale in new project remains limited so far. Uncertainty regarding the availability, reliability and liability of secondary materials as well as a challenging carbon-impact analysis seems to outweigh potential benefits for now.

Closing the material loop requires innovation in the field of the de-/assembly process and the development of long-lasting, sustainable and versatile materials. Europe's existing infrastructure and building stock provide ample opportunities for urban mining and the emergence of a circular built environment. Establishing material recovery routes and industrializing deconstruction processes is paramount for increasing material reuse rates. Complementing deconstruction with the development of novel and bio-based materials that can easily be recycled, reused or refurbished will enable a circular construction industry.





Frameworks like Level(s) and standards e.g., CEN/TC 350; BS EN 15978:2011 increasingly draw attention to the life-cycle assessments (LCA) of buildings. Yet a common nomenclature and understanding of what and how different stages of an asset‘s life cycle are considered requires further development ***[20]***. Additionally, legal guidelines on how secondary materials can be reused, refurbished and recertified and successfully fed back to the material cycle without open liability need advancements. Spurring integrative research and developing LCA standards and material reuse, refurbishment and recertification schemes is a vital frontier for a circular built environment. Lawmakers and regulations are considered a vital enablers for the emergence of a circular built environment and have to answer the call coming from industry ***[19]***. Political and, in turn, legislative pressure is increasing in order to facilitate a transition towards a green and sustainable economy. As a key value chain in the EU’s circular economy action plan, the construction industry will face a new wave of new regulations that foster sustainability.

As a key value chain in the EU circular economy action plan, the construction industry is vital for the transition towards a green economy. While recycling quotas advanced construction and demolition waste management in recent years, quotas propelled downcycling practices within the construction industry. Proposing LCA according to Level(s) and EN 15978, design for adaptability ***[15]*** and deconstruction ***[16]*** assessments and mandatory recycling quotas in the taxonomy on sustainable finance spurs the demand for reused construction materials.

In contrast to integrated supply chains like the automotive industry, the architecture, engineering and construction (AEC) value chain is highly fragmented due to the heterogeneous body of knowledge and skills that cuts across various fields. The built environment ecosystem is governed by loosely coupled stakeholders making decisions in isolation to maximise personal gains ***[17]***. This resulting competitive and price-driven environment has resulted in a siloed approach to service delivery promoting a linear take-make-use-dispose operating model with limited feedback loops. Switching towards coordinated decision making regarding material, design, de-/construction, operation and end-of-life activities across multiple stakeholders is paramount for advancing circular solutions in construction ***[13]***. Making circular construction happen requires building new standards, increasing traceability and transparency, and trust within the ecosystem.

The prevalence of x-as-a-service business models in the built environment provides a solid foundation for the emergence of a circular construction framework. However, long life cycles of certain building materials such as bricks harbour uncertainties that set boundaries to circular business cases and the underpinning return-on-investment calculations. The emergence of collaborative models of all engaged stakeholders complemented with flexible contractual and ownership arrangements are key in developing circular built environment business models ***[18]***. Conducting a thorough value stream analysis will reveal each stakeholders’ costs and benefits of a circular built environment and opportunities to develop profitable and sustainable business models ***[19]***.

MATERIAL SUBSTITUTION

UPONOR BLUE:
BIOBASED PLASTIC PIPE SYSTEMS
Manufacturer: Uponor Corporation

Project Information

Uponor Blue product portfolio includes world's first plastic pipe systems based on renewable and residual material feedstocks with an ISCC certification of the raw material and feedstock supply chain. The products are manufactured using raw materials refined from forestry and agriculture residual material streams, waste fat from food industry, used cooking oil, and other secondary material streams. First solutions in this portfolio are intended for use in plumbing, heating and cooling, storm water and sewer applications. Carbon footprint impacts of material substitution have been evaluated through externally verified Environmental Product Declarations (EPD), and these show 70-90% carbon footprint reduction compared to standard alternatives.

More here:

www.uponor.com/en-en/uponor-blue

Learnings

Efficient material substitution requires in-depth collaboration through the value chain from initial feedstock acquisition, raw material refining and product manufacturing. Transparency is essential in order to ensure that all steps in a potentially complex value chain are operated in a responsible and sustainable manner.
Independent evaluation and certification of the value chain, in this case ISCC certification, provides credibility and trust for new solutions. As new feedstocks and raw materials are introduced, new research needs also emerge to ensure comprehensive understanding of their environmental and social benefits and impacts compared to traditional alternatives. New renewable feedstocks still come with a price premium: the unit price of biobased products is currently 20-30% higher compared to standard alternatives.

INDUSTRIAL SYMBIOSIS FOR SOIL IMPROVEMENT

MELIDE – PALAS DE REY PROJECT:
SOIL IMPROVEMENT WITH ASH
Contractor: ACCIONA Construcción, S.A.
Property Owner: DG CARRETERAS
(MINISTERIO DE TRANSPORTES) - SPAIN

Project Information

Two pilot sections have been carried out for the Melide - Palas de Rey project (Spain) to demonstrate the technical, environmental, and economic feasibility of using biomass ashes due to their chemical properties as an alternative to conventional hydraulic road binders. The appreciable content of reactive calcium found in biomass ashes and its binding and stabilising capacity, together with the adsorbent properties of this fly ash, make it of great interest to replace lime and cement in the stabilisation and improvement of soils in civil works. The CO2eq (kg) emissions per 3 % of the lime are 82,031; on the other hand, The CO2eq (kg) emissions per 3 % of the fly ash are 5,521. Therefore, replacing the lime with fly ash in soil stabilisation will result in a 93 % reduction in GHG. This ash valorisation option is one of the most beneficial ways to take advantage of biomass fly ash characteristics.

Learnings

Valorising biomass ashes as an alternative hydraulic road binder has some legal and standard obstacles in Spain. However, despite these obstacles, this type of execution reduces the consumption of raw materials and GHG emissions to the atmosphere that is produced due to the manufacture of cement. Furthermore, proper mixing, handling, and use during construction make the potential risk for humans and ecosystems disappear. In addition, it fosters a Circular Economy model by taking advantage of a by-product produced in industry and favours its commitment to “Zero Waste”. Compared with the standard lime addition, the biomass ash showed an improved ability to retain trace elements (Ni and Cr) naturally leached out from the soil, keeping the values below the threshold permitted limits. By eliminating the cost of cement, the savings on the unit of work are significant. But there is another indirect saving: the replacement of cement with fly ash decreases the reference density of the material once compacted, which leads to a higher yield of the latter.

03.03.

Circular economy in construction

Applying circular economy principles to the built environment poses several challenges. Next to the different levels ranging from material to building and city or regional level, the temporal ranges of asset's layers add to the complexity of the task. Variations in service life of building materials in the context of an assets life-cycle encourages flexible designs to provide opportunities for convenient dis-/assembly. The shearing layer model highlights the temporal nature and service-orientation of site, structure, skins, services, space plan and stuff layers of buildings ***[21]***. Segregating assets to components provide several opportunities to promote circular construction. Using temporary joinery like nuts, bolts and screws instead of glue allows cost-efficient renovation/upgrading works and salvaging of high-quality materials for refurbishment and/or reuse. Moreover, the capability of an asset to be disassembled paves the way for shared ownership arrangements. Consequently, individual layers and components can be owned and operated by different stakeholders. In turn, investors can outsource the financial risk associated with owning and operating different layers. In short, adopting a layer-perspective on assets promotes design for disassembly and thus a solid ground for the technical and economic foundations for a circular construction industry.

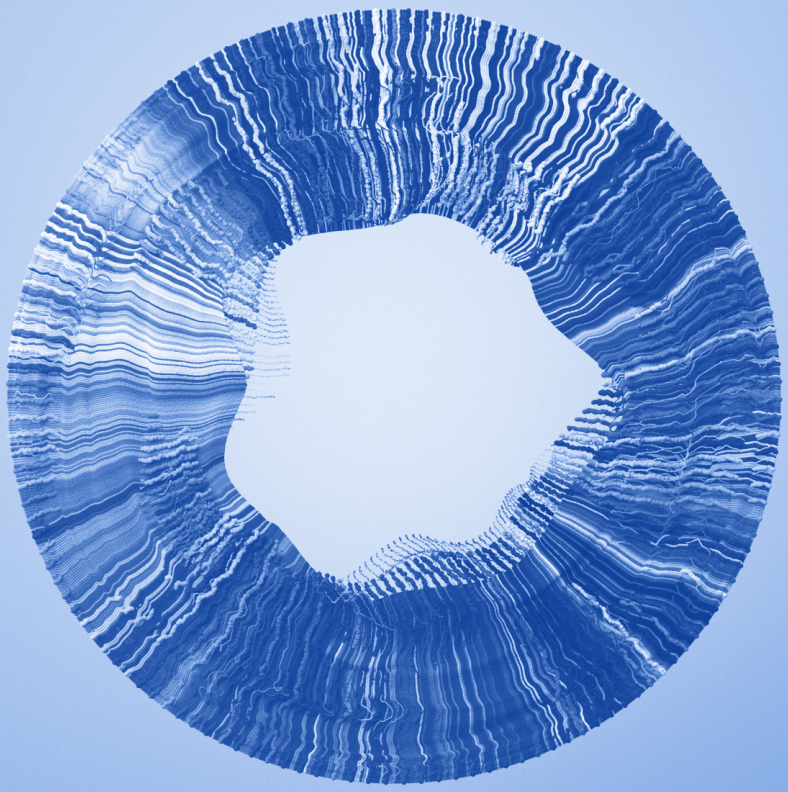
Reusing, repurposing, or recycling materials at a high economic and environmental value level is at the heart of circular economy. While great progress has been made on increasing the construction waste and recycling rates within the EU in recent years, the economic and ecological value retention remains limited. Downcycling extends the lifetime of materials, yet the ecological and economic value is depleted after few cycles. Consequently, the almost linear relationship of construction volume and the demand for extracted and processed raw materials continues. For decades, demolition contractors and waste collection services have already taken advantages of shadow prices of construction and demolition (C&D) waste. Collecting disposal fees while selling downcycled C&D waste, mostly as filler material, provides redundant revenue streams and thus a reliable business model. Disassembling, sorting and refurbishing and recertifying, all steps necessary to reuse salvaged materials, has been discarded because the labour-intense and often complex processes associated with these steps. Closing the material loop requires a set of measures from material manufacturers and distributers, general contractors, demolition contractors and investors to decouple material consumption from construction output.

Repurposing concrete, wood and glass waste streams by leveraging a network of partners has been proven to be profitable, although requiring upfront R&D investment *[22]*. In a similar vein, economically viable cases have been made for mechanical steel connections for concrete elements encouraging reuse, design for disassembly windows, and circular roof felt from material manufacturers *[14]*. Taking advantage of the latent value inherent in repurposing or reusing as well as growing interest in building materials with a lower climate impact has spurred the development of viable circular material business models.

Material manufactures can gain from a circular construction ecosystem. Refurbishing and/or repurposing building materials with short- to mid-range lifespans provides ample opportunity to significantly reduce material consumption, the carbon footprint and in some case even create a lock-in for customers. Designing products for disassembly, refurbishment and without waste offers a solid foundation for prolonging the service-life of materials and for x-as-a-service business models. However, switching from number-of-units-sold towards an installed-and-maintained-base revenue model will not remain unencountered since it cannibalizes incumbent revenue streams and business models.

Material-as-a-service business models enable investors to reduce capital expenditure, allows for handing down operational cost on a costs-by-cause-basis to tenants, and eradicates the obsolescence risk associated with owning materials and installations that are of uncertain future value. For instance, a HVAC-as-service model allows investors to significantly reduce building costs as well as outsource operation and maintenance to an effective specialist. In turn, HVAC (Heating, Ventilation and Air Conditioning) suppliers gain interest in manufacturing and installing durable, easy to maintain, reliable and easy to disassemble systems. Contractual frameworks covering scheduled service intervals, up-time and an adequate remuneration logic can be modelled from elevator service agreements. In short, by applying circular economy principles material manufactures reap benefits like *(a)* reducing virgin material consumption, *(b)* decreasing carbon footprint, *(c)* securing a reliable source of (semi-) manufactured materials, *(d)* expand business in operational services and maintain long-lasting customer relationships.

Amongst the major challenges for material manufacturers is to *(a)* design materials and products for disassembly, *(b)* ensure compliance with installation guidelines in the construction phase, *(c)* facilitate non-destructive maintenance and disassembly, *(d)* organize reverse logistics, *(e)* establish refurbishment and recertification processes and facilities, and *(f)* hedge the material obsolescence risk. Advancements in construction material circularity at a European level require a critical mass of manufactures to engage in coordinated schemes. An extended material responsibility (EXR) for manufacturers/contractors where responsibility includes post-consumer life cycle stages, provides a potential legislative leverage. Material manufacturers need to be adequately incentivized to take environmental concerns into account when designing and combining construction materials. As a result, economic and environmental costs can be internalized in the price of the construction material/service and, in turn,make circular business models more viable.



The long-term focus of circular assets enhances the principle-agent problem in client-contractor relationships. Investors' aim to ensure low-impact operation and high circularity extends contractors' responsibilities to the end of assets' lifecycle. The dominant pay-for-progress transactional model between investor and general contractor needs to incorporate several long-term pricing components. First, contractors' remuneration can be dependent on achieved operational performance, e.g. energy efficiency, within the first ten years of assets. Since energy efficiency is influenced by operational parameters beyond the influence of the contractor, adequate measures need to be defined. Second, the ease and related costs of renovation of individual building layers, can provide another anchor for a pricing mechanism. Finally, at the end of assets' service life, ownership of the material and the rights and responsibilities of reuse or disposal can be financially represented with a convertible material bond. This way, general contractors can take advantage of investments in design for disassembly while mitigating the risk of material obsolescence. In a similar vein, arrangements in cooperation with material manufacturers like options can help general contractors to bridge the temporary disparities from design and construction to disassembly and the inherent future monetary value of materials.

These suggestions pose a stark contrast to the short-term profit focus of most general contractors. In addition, threads of business model cannibalization due to the advancements of design for deconstruction and modular systems need to be mitigated. Standardization and documentation of building material in the existing building stock open doors wide for generative design-aided planning, systematic urban mining and a well-functioning (over-)regional circular material market.

There are a few fundamental ways to increase the circularity of buildings and construction materials. For new construction, it is imperative to apply material substitution and designing for flexibility while minimizing waste. Material substitution is used to increase the use of bio-based, recycled and reused materials. Flexibility in design covers a wide range of somewhat intertwined design methods aiming at increasing the adaptability of a building and/or ease of disassembly [23]. Over time, the functional requirements of a asset may change. To ensure an assetprovides a relevant use, modifying its layers becomes necessary. Making this modification easier by incorporating the capacity to change the asset's layout is the goal of design for adaptability. This can be achieved by separating asset elements, using interchangeable components, oversizing construction elements and through designing for disassembly [24]. While designing for disassembly can be used to increase the adaptability of an asset , it is also used to allow for reuse and recycling of building components and materials. However, the largest challenge for circular construction lies with the existing building stock. Extending the service life of assets and components through renovation and disassembly will be crucial moving forward. While extending assets' life and their individual components is at the heart of a circular construction industry, buildings and structures are considered as one of the most underutilized asset categories.

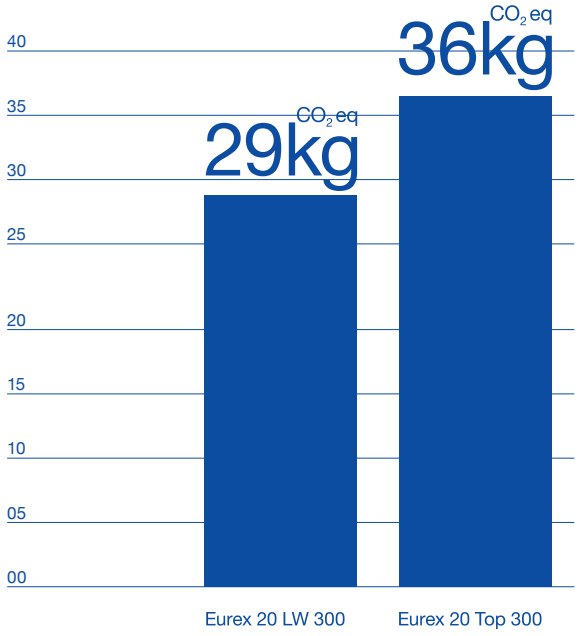
Clearly, there are many pieces needed to complete the circularity puzzle in the construction industry. Defining pieces that squarely fall within ENCORD's purview is that of disassembly and deconstruction, material substitution and efficiency, as well as renovation and retrofit.

PRODUCT CARBON FOOTPRINT

As part of Doka's commitment to sustainability and the company's ambitious goal of achieving net zero emissions by 2040, we recognise the importance of addressing our customers' carbon footprint needs. Here is an example: A contractor participating in a public tender requires information on our products with the lowest carbon footprint. Fortunately, as part of the Product Carbon Footprint (PCF) initiative, Doka has calculated the carbon footprint of 6,000 individual products over their life cycle. This comprehensive assessment in accordance with ISO 14044 includes the extraction, production and transportation of raw materials and pre-products as well as end-of-life.

Moreover, by leveraging the PCF data, we gain valuable insights into the CO_2 hotspots throughout the lifecycle of each of our products, empowering us to systematically implement measures that significantly reduce their environmental impact. This knowledge also drives the development of more climate-friendly products tailored to our customer's needs, which is a key part of our climate strategy. Furthermore, analysing the PCF proves invaluable in identifying the climate impacts associated with circular approaches.

Product Carbon Footprint
Doka GmbH



Comparing the greenhouse gas emissions of different products: By providing Product Carbon Footprint data this is now possible for 6,000 Doka products. Such as the Doka Eurex LW floor prop. Using high-strength steel and state-of-the-art production results in the Eurex LW floor prop weighing significantly less than common tubular steel props. This reduces greenhouse gas emissions and provides ergonomic benefits for the user. And all this with the usual performance and durability.

Our solution and USP

- CO_2 emissions of our products upon request of our customers
- Possibility of internal product comparison, enabling the ordering of the product with the lowest CO_2 impact
- Better ratings in supplier assessment & scoring
- Basis for more climate-friendly product development and accurate reduction measures

Deconstruction can improve the material efficiency in construction significantly while providing the same levels of performance. Despite the various social, economic and environmental benefits of design for disassembly, salvaging construction materials has mostly been limited to a few product types so far ***[13]***, ***[25]***. Only by enabling deconstruction at scale are we able to contribute to the preservation of valuable materials which are stored within current and future built assets. With a changing regulatory landscape and dynamic/volatile market prices of building materials, storing and unlocking that intrinsic value becomes a necessity.

To enable deconstruction, the following four aspects need to be considered: design for disassembly, building for deconstruction, the deconstruction process as well as reuse and recycling of construction components and materials. The extended service-life and permanent nature of buildings and infrastructure rendered end-of-service-life considerations of building materials as well as the need to separate them again obsolete. Consequently, building processes are steeped in the make-use-dispose logic and favour easy-applicable adhesive-based joinery of individual materials. Replacing glue with screw and plug solutions wherever possible allows for the easy disassembly of building and infrastructure elements. As a result, the efforts required to refurbish or renovate building stock can be minimized and thus increase the long-term value of the assets. Moreover, the ability to salvage high-quality materials from buildings and infrastructure, as material banks, and in turn minimize the disposable waste further increases the value of an asset.

04. Deconstruction

Design for disassembly

The design for disassembly, sometimes referred to as design for deconstruction or design for reuse, has been described theoretically and the principles are well understood *[26]*, *[27]*. The key principles generally boil down to using accessible and reversible connection details between recyclable and reusable materials and components. In addition, building parts and components should be layered based on expected service life while using fittings, adhesives and sealants that allow for disassembly. In order to enable future disassembly, BIM can be used to standardise and store information regarding material characteristics and disassembly through material passports *[28]*.

Building for deconstruction

To enable the key principles of designing for disassembly the building process needs to be adapted. More prefabrication brings different demands on construction logistics and considerations regarding work-site safety. There should also be clear economic benefits to building for deconstruction as it typically results in reduced building complexity and improved buildability. Moving from demolition and destructive renovation to disassembly and selective dismantling poses several challenges for the deconstruction process.

Reuse and recycling

To enable reuse and recycling of deconstructed building materials and components, changes are needed throughout the value chain, which will require modifications to existing business models. A functioning market for salvaged building materials is paramount for a circular construction industry yet it remains absent so far. At the heart of a functioning market coordinating the temporal and spatial variations in the supply and demand of salvaged building materials is a cost-reflective pricing mechanism. Being capable of assessing the current and potential future value of building materials and thus the residual value of assets, will incentivize public and private investors to increase the “degrees of circularity” on their investments.

DESIGN FOR CIRCULARITY

Parking Delft Univercity Contractor:
Ballast Nedam

Project Information

The modular parking garages provide temporary capacity and are designed for disassembly. The system is customizable and has a short construction time using flexible connections to connect prefabricated elements. With a standard set-up rent/buy-back schemes are available. Without a need for a compression layer of corrugated sheets, CO_2 savings of up to 20% can be achieved. Ballast Nedam has built a parking garage that will be in place for ten years. Due to its temporary nature, the garage has been built using modular materials that can be dismantled and reused in accordance with the MODU park system developed by Ballast Nedam. This garage can be completely disassembled after use and rebuilt elsewhere. In addition, the green façades harmonize with the wooded setting, reduce noise and capture particulate matter. Nesting boxes for birds, bats and bees have also been built into the façades.

Learnings

The inherent circular design principles also create a financially attractive second-hand market with lower precis and predictable construction costs. Having a structure that can be disassembled lowers cost for re-developing terrain and the flexibility also allows for expanding or shrinking the garage based on request. The preparation time is also reduced compared to standard construction of garages.

Material substitution is required to increase the circularity of construction materials and limit the need for virgin materials as the global building floor area is expected to double by 2060 *[29]*. This can be achieved by moving to products made of renewable bio-based materials and products consisting of recycled and reused materials. The increased use of new circular materials and products will provide challenges related to cost efficiency, (perceived) technical performance and risk of containing hazardous substances as outlined by the European Environmental Agency *[30]*. The proposal by the European Commission to revise the Construction Products Regulation (CPR) will require new products to be designed and manufactured in a way that makes them more durable, easier to repair and re-manufacture and recyclable. Measures are also needed to limit the use of material resources and waste flows through more efficient construction processes.

Using recycled and reused materials

To reduce the need for virgin materials and limit waste, reusing products and materials or using products containing recycled material is necessary. When using recycled and reused materials and products, it is important to ensure environmental benefit and economic viability. Yet, environmental benefits of reducing the use of virgin materials may be offset by increased transport demand and reconditioning requirements. For financial viability, it may be necessary to adapt current business models to remove barriers and capitalize on the intrinsic economic and environmental value by considering the entire value chain *[40]*. The proposed revision for EU's Construction Product Regulation (CPR) contains obligations regarding minimum recycled content of construction material, giving preference to recyclable materials and designing products that enable remanufacturing and recycling which may serve to speed up the adoption of recycled and reused materials.

Bio-based materials

Bio-based materials provide multiple functions as they can be reused and recycled or returned to the biological cycle by composting while providing a potential reduction of CO_2 emissions by being stored in buildings over long time periods *[31]*. Substituting dominant construction materials with energy-economic and/or regenerative alternatives, e.g. cement with hempcrete *[32]*, *[33]* or agro-cement *[34]*, *[35]* and steel with basalt-rebar *[36]*, *[37]* or even natural fibres *[38]*, *[39]*, hold the potential to significantly reduce the sector's non-renewable resource consumption and carbon footprint.

Material efficiency

The construction industry is one of the largest producers of waste in Europe.
To meet targets on waste reduction set by the European Union, a higher degree of material efficiency is needed. Material efficiency aims at optimizing waste generation and material usage of a building project by careful planning and design to minimize spillage and avoid excess material. Using prefabrication and a stationary production environment can result in less waste at the construction site.

05. Material Substitution and Efficiency

06. Renovation

Integrating circular principles in new constructions has many potential benefits. While circular construction climate mitigation impacts have a significant lead time there is an urgent need to lower emissions now. Applying circular design principles such as design for disassembly is one example of a circular measure that will provide benefits once the new building reaches the end of its life cycle. Due assets' long lifespan, this benefit will occur 50 to 100 years from today. Thus, it is of great importance to prioritize renovation and maintenance of the existing building stock and infrastructure which yields a more immediate impact. It is estimated that more than 85% of today's assets are likely to still be in use in 2050 ***[41]***. The existing building stock and infrastructure provides opportunities for adopting several circularity principles. Extending the lifespan of assets via renovation and maintenance measures or improving assets' utilization by converting them will delay the need for demolition and subsequent new construction. Inherently, the need for material is also reduced as new construction requires more materials than reconfiguring existing assets. One example would be converting office space to residential units in a post-pandemic setting where how and from where we work has decreased the utilization of office space.

In order to achieve the EU green deal goals, Europe's current building stock requires significant energy efficiency improvements. Renovation and repurposing of existing assets provide a low-impact means to improve energy efficiency and utilization, while overaged assets and their inapt structures can be disassembled and strategically mined for valuable construction materials. Extending the service life and utilizing the existing European building stock is key in achieving a circular construction industry by limiting the need for new construction. In addition to the circular benefits of utilizing the buildings and infrastructure that already exist, renovation provides an opportunity to improve energy efficiency and tackle fuel poverty. This is also emphasized by the Renovation Wave as part of the European Green deal, aiming at doubling the annual energy renovation rates in the next ten years.

REUSE OF CONSTRUCTION MATERIAL

Project Information

The visitors centre at the Onsala Space Observatory outside Gothenburg, Sweden have been renovated and expanded with the aim to showcase the reuse of construction material. Rather than design a building based on available reused material, a conventional design process was applied in conjunction with using networks and digital platforms developed for reused construction material. The need for new material and virgin resources have been substantially reduced in the project. In total, roughly 40% of all construction material (by weight) comes from reused products which resulted in a 35% reduction of greenhousegas emissions.

Learnings

Reuse of construction material is fraught with legal, technical and financial issues. However, despite these obstacles it is entirely possible to achieve a high degree of reuse at no additional cost. The success factor in this case has been the local networks that exist for reuse rather than the digital marketplaces. Reuse of certain materials proved to be more challenging, specifically steel where only 15% reuse was achieved due to difficulties finding steel in the correct dimensions that had been disassembled without being damaged.

VISITORS CENTER AT THE ONSALA SPACE OBSERVATORY
Contractor: NCC AB
Property Owner: Chalmersfastigheter AB

To achieve a circular industry, construction needs to modify the way assets are constructed, but also work to reform the way the industry is structured: The types of companies involved in the project delivery, the types of contacts and transactions between parties, the underlying business models. A transition towards a circular construction industry is already underway.

The question of how the construction industry can enable and adapt to that transformation has been posed to the working groups of ENCORD. While not complete or holistic, it does provide unique insights from ENCORD into the enablers identified for a circular transition. Below are the key aspects highlighted by the working groups.

Digital built environment

To enable a transition towards a circular construction industry data and standardization will be key. This transition can be aided by focusing on product data templates, maintaining and deploying this data and following standardization regarding building logbooks and material passports. Digitalization is being pushed as an enabler not just regarding circularity but in a wider sense as well and can be structured by Use case Management. Transparency and trust in data are key features and may be supported by technologies such as blockchain.

Data will be a new raw material. Firms and organizations will buy, sell data and trade data. There will be data miners, data controllers, data brokers and data wholesalers. How new data-driven business models will change the AEC industry, and if circular business models will emerge, is hard to tell. We can see that we are at a tipping point. To avoid commoditization, the largest global players try to move up the ladder, from asset builders and service providers to technology creators and network orchestrators. They've understood they can diversify their sources of revenue by creating value-added circularity-related services

07. Enabling and adapting for a circular construction industry

Foresighting

If we are to become a more circular industry, construction needs to respond to several challenges. These include changes to the way assets are constructed, the creation of viable circular marketplace materials and a real-time understanding of what materials will be available for use at any given time (some of which may not come from the construction industry).

Foresighting helps us to explore what this might look like in practice and the barriers and opportunities this may offer the industry. It also allows us to determine what steps might be required to get us from today's business as usual to a circular construction industry. As a workgroup we have started to consider what the circular economy might look like in construction by 2030.

We have examined several possible forms of circularity: getting more out of existing spaces, design for deconstruction and what to do with the many existing buildings, which vary in quality. All of these will require a change in the way we and others think and do things, many of which we need to start addressing today if construction is to successfully adopt circular. For example, if we are to get more out of existing spaces, we will need to change building designs, leasing contracts and planning regulations to support a more flexible use of space.

One of the main barriers we have identified in our research is the need to establish effective materials streams, which will enable us to have enough materials for reuse on projects. Currently, there is a lack of understanding about the materials stored in our existing building stock, and it's not feasible to store large amounts of materials until they are needed. Digital twins will resolve some of these issues on newer schemes, but we still don't know what materials are in existing assets that could be salvaged.

One solution could be a citywide database and marketplace, which captures the materials in existing assets and their likely demolition dates, giving designers the chance to create assets that utilize materials as they become available. To support this, we would also need a functioning marketplace to link contractors with materials, some of which may come from other sources outside of construction.
Finally, we need to consider how we change end-user perceptions and expectations. Second hand never looks quite as shiny and bright as a new item and there can be a stigma attached to reused items. As an industry, we need to manage this process and bring end users on the journey towards embracing circular buildings as something just as desirable.

Technological advancements in construction have great impacts on productivity, but we need to consider other key aspects: the adaptation of business models, the transformation of organizations and changes in behaviours ***[42]***. To achieve a more circular industry, construction needs to modify the way built assets are constructed, but also work to reform the way the industry is structured. The types of companies involved in the project delivery, the types of contacts and transactions between parties and the underlying business models need to be radically different. The focus will be on the value delivered to the ecosystem ***[43]***. To stay ahead of the competition, to grow and to maintain profit margins new business models are considered as a real possibility ***[44]***.

LEAN

Lean provides a formal assessment framework and wider holistic understanding of “waste” compared to those traditionally associated with socio-environmental or sustainability impacts. Lean is not a silver bullet but it can provide a framework for continual improvement. This is particularly relevant as the pressures on our planet increase.

Construction stakeholders will perceive different and often conflicting risks or opportunities. By actively engaging all stakeholders in the journey, Lean can provide a formal process for consensually achieving the most considered benefits and outcomes. Lean decision tools such as Choosing by Advantages (CBA) can be used to assess the validity and value of projects prior to contract and commitment to projects to support sustainable decision-making.

Health and Safety

Moving towards a circular construction industry requires adopting to a new way of working. This transition comes with both new and shifting risks as well as benefits from a health and safety perspective (H&S). Early process integration of H&S topics within circular construction and specifically within the topic of deconstruction is essential including on-Site Diagnostics of materials, structure, reuse options and measurements in existing buildings. With the topic of deconstruction, we must also consider risks relating to the reuse of hazardous materials and chemicals or whether destructive methods need to be used.
In addition, new products and possibly chemicals need to be considered from a H&S perspective. There are also clear potential benefits where an increase of modularity with a higher share of standardized off-site manufacturing will have positive effects on health & safety due to higher workshare in a uniform manufacturing environment.
Strategic “make or buy” decisions in the field of deconstruction and recycling will have to be reconsidered. Today, this work is typically outsourced to sub-contractors based on the lowest cost point. In the future, material availability and an increased value of recycled material will change toward a higher share of in-house processing. Therefore, the overall know-how needs to be increased. In general, H&S competence for all involved functions is currently not sufficient for the coming changes and need to be increased and developed. This will most likely also lead to new job profiles.

The key enabling factor for circular construction is a viable business case.
The demand for circular designed and assets from public and private investors will only increase when any cost premiums are outweighed by tangible future returns. While supra-national regulations like the EU Taxonomy are acting via ecological and social bottom lines as a proxy for economic viability, few cases have been made for enticing business opportunities in circular construction yet. Evaluation practices need to put an emphasis on assets‘ aptitude to be efficiently renovated during and salvaged for materials after their lifetime.

Commonly, assets are priced by discounting projected returns based on the assumption of future demand. Thus, in increasingly volatile markets versatile building designs that can be efficiently converted and/or renovated certainly qualify for premium construction prices. Likewise, changing mobility habits and advances in autonomous vehicles are likely to increase the efficiency of existing infrastructure, potentially freeing up capacities to be repurposed. For instance, on-demand individual mobility enabled by autonomous driving cars will significantly reduce the need for inner-city parking that can be converted to green spaces. This obsolescence risk of assets can be mitigated by applying design for deconstruction principles leveraging mechanical screw and plug connections. The resulting assets’ capabilities to be repurposed, repaired, upgraded and disassembled allow for the extension of functionalities while maintaining material value retention rates. In short, adequately incorporating assets’ versatility in evaluations is a cornerstone of advancing the circular construction business case.

In short, for a solid circular asset business case for investors, evaluations must incorporate assets’ versatility and the value of to-be-salvaged material stock. As a result, assets’ residual value can increase significantly and in turn reduce assets’ depreciable amount over the expected lifetime. The subsequent increase in assets’ annual profits raises investors‘ tax burden over potential returns from uncertain demand in the asset and ambiguous salvaged material value. Changing the fundamental assumption of “residual value of an asset is often insignificant and therefore immaterial in the calculations of the depreciable amount” [45, p. 1148] is key in creating a viable circular business case. An increase in assets‘ forecasted residual value diminishes short- to mid-term profitability, asset managers’ compensation packages, and investors’ current revenue models. Therefore, incorporating circularity metrics and associated scientifically proven carbon savings in evaluations of assets is paramount for asset holders’ governance structures and incentivizing a circular construction business case. For instance, a green evaluation premium would add to the depreciable amount and thus can (a) internalize environmental externalities and (b) offset and/or mitigate additional construction costs incurred by circular construction practices. At the same time, subsidies and/or tax breaks for circular assets provide another lever similar to the EU Taxonomy. A purposeful-oriented incentive system for investors is vital for the advances of circular construction practices.

Most of the architecture, engineering and maintenance companies provide services to their clients, while construction firms build physical assets. With difficulties to stay head of the competition, to grow and to maintain their margins, most of the large architecture, engineering, construction and operations companies consider new business models as a real possibility. Yet, the transformation of a business model is a long journey and not all companies are agile enough and have enough investment capabilities to pivot toward new business models.

Circularity is currently perceived as another insurmountable new transformation. For incumbent construction companies, the way things are done, traditional behaviours, customs and prevailing orthodoxies need to be disrupted. Innovation comes in different shapes, and circularity is just another form of innovation. With more data available, new business strategies, and new ecosystems, circularity in construction might not be a challenge as insurmountable as it seems.

08. Conclusions

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