CIRCUIT

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Increasing the reuse and recycling of building materials

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Contents

Acknowledgments

The *Circular Construction in Regenerative Cities* report presents the key learnings, tools, methodologies and recommendations generated by the Circular Construction in Regenerative Cities (CIRCuIT) project from 2019 to 2023 across the cities of Copenhagen, Hamburg, London and Vantaa/ Helsinki region.

This report was produced by members of the 31 partner organisations that were involved throughout. It shares a body of work that was made possible thanks to the time and expertise provided by numerous individuals who helped to support the project across its lifespan. This includes local decision makers and built environment stakeholders from each of the CIRCuIT cities, as well as the European Commission's Horizon 2020 programme.

All of the resources presented in this report, along with the accompanying technical report, are available at circuit-project.eu/post/latest-circuit-reports-and-publications.

Glossary of terms

Adaptive Reuse
The process of reusing a structure or building for a purpose other than the original purpose for which it was built or designed.

Business as Usual (BAU)
Shorthand for the continuation of current conventional construction process practices as if the intervention under consideration were not to happen. Usually used as a benchmark to compare interventions.

Circularity Indicator
A piece of information that can be used to measure performance within the built environment to guide decision making and enable the industry to communicate their circular economy actions in a consistent way.

Design for Adaptability (DfA)
An approach to planning, designing, and constructing a building so it can be easily maintained, modified and used in different ways or for multiple purposes throughout its lifetime, extending its practical and economic life cycle.

Design for Disassembly (DfD)
Approach to the design of a product or constructed asset that facilitates disassembly at the end of its useful life in such a way that enables components, materials, and parts to be reused, recycled or, in some other way, diverted from the waste stream.

Downcycling
A form of recycling that repurposes materials into a substance of lower value than the original.

Life Cycle Assessment (LCA)
A methodology developed to assess the environmental impacts of a building, component or material. The assessment compiles and evaluates the inputs and outputs of the material system throughout its life cycle and assesses the relevant environmental impact.

Life Cycle Cost Analysis (LCC)
An analysis of all the costs that will be incurred during the lifetime of the product, work or service. LCC may also include the cost of externalities such as environmental degradation or greenhouse gas emissions.

Meanwhile Use
A range of strategies to make under-utilised spaces and places productive, both economically and socially, often for a shorter length of time until a long-term use for the space is determined.

Pre-demolition Audits (PDAs)
A systematic and comprehensive assessment conducted before the demolition or deconstruction of a building or structure which results in the inventory of materials and components arising from the building. The reusability and recyclability of the materials can also be assessed during this process.

Pre-redevelopment Audits (PRAs)
A systematic evaluation conducted before the redevelopment or repurposing of a property or site, typically with the aim of assessing and addressing potential environmental contamination and regulatory compliance issues. The potential to reuse or incorporate existing structures on site into the new plans can also be assessed during this process.

Recovery
The process of systematically and intentionally collecting, salvaging and reusing materials from a building or construction site to extend their life cycle and reduce waste.

Recycling
Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes.

Return on Investment (ROI)
The quantifiable returns and advantages derived from embracing specific construction methods. This encompasses financial gains, environmental benefits and enhanced social value resulting from the project's design choices.

Reuse
The repeated use of a product or component for its intended purpose without significant modification.

Transformation
In architecture transformation is used as an umbrella term to refer to a wide range of potential changes to a building from a subtle change of appearance to a complete change of use.

Upcycling
A form of recycling that repurposes waste, products or materials into a substance of higher value than the original.

Urban Mining
The process of recovering and reusing the raw materials that are already in the environment, cities or everyday products, in the resource cycle.

Introducing the CIRCuIT project

The way we currently build our cities is wasteful and inefficient with resources extracted, manufactured into components, and constructed into buildings only to be demolished and discarded as waste well before the end of their useful life.

Estimates suggest that 11% of global emissions are linked to manufacturing construction materials such as steel, cement and glass[1]. In the EU alone, the built environment accounts for 36% of carbon emissions, 40% of material use and 50% of landfill waste[2].

Accommodating for the expected population growth within cities will mean constructing additional buildings and infrastructure equivalent to a city the size of Milan (1.5 million people) every week until 2050[3]. There is, therefore, an urgent need to transition from a linear construction model to a more sustainable and regenerative one based on circular economy principles.

In a circular model, rather than continuing the traditional take-make-consume-dispose process, building material loops are closed through reuse, sharing, leasing, repair, refurbishment, upcycling or recycling. This radical reimagining of construction considers how the lifespan and reusability of entire buildings can be maximised at the very start of the design process and thereby ensures that usable materials are not discarded as waste.

Cities hold the keys to this transition. Working collaboratively with industry, they can find new ways of confronting the climate impact of construction and develop a new urban agenda. This also gives rise to co-benefits as embedding circular principles also supports wider policy goals such as net zero targets, climate resilience and adaptation in cities.

Further, this regenerative approach has economic and social benefits as more adaptable and flexible cities are better able to serve the changing needs and interests of residents and circular solutions often also bring cost savings over a building's life cycle.

It is, therefore, crucial that cities and their stakeholders have the support, resources and tools needed to create change and drive circular construction practices locally.

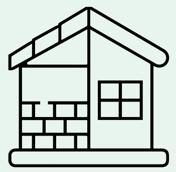
Turning theory into practice

Many circular construction techniques, tools and approaches have been developed and tested around Europe, but circular practices are yet to be scaled up effectively to a city or regional level. To explore how the circular economy can be effectively embedded in cities across Europe, and bridge the gap between theory, practice and policy, CIRCuIT – Circular Construction in Regenerative Cities – was established.

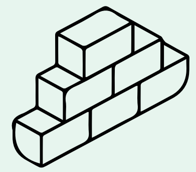
CIRCuIT was a collaborative project funded by the European Commission's Horizon 2020 programme. The project involved 31 partners across the entire built environment supply chain in Copenhagen, Hamburg, Helsinki Region and London.

1 Global Status Report for Buildings and Construction 2019 | IEA
2 Internal Market, Industry, Entrepreneurship and SMEs | European Commission
3 Circular economy in cities: Opportunity & benefit factsheets | Ellen Macarthur Foundation

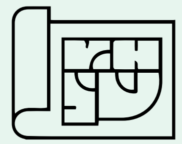
The project's goal was to support the mainstreaming of circular construction practices in the built environment focusing on three key thematic areas:



Transformation and building life cycle extension



Urban mining and material reuse



Design for disassembly and adaptability

Over the course of the project three key results emerged:

1. It is beneficial: Circular practices can improve both the financial and environmental outcomes of construction projects. As part of the project, 36 demonstrators were developed that provide evidence of the carbon and economic implications of adapting conventional construction methods to more circular approaches. The results show that the environmental benefits are great: in all three thematic areas there can be significant carbon emissions reductions and resource savings. Cost benefits are also evident within the context of a circular approach and have been explored in the business cases within chapters 1, 2 and 3. Shifting to circular practices requires use of long-term thinking and seeing buildings as investments to be examined by legislation, integrated collaborations, and new financial models.

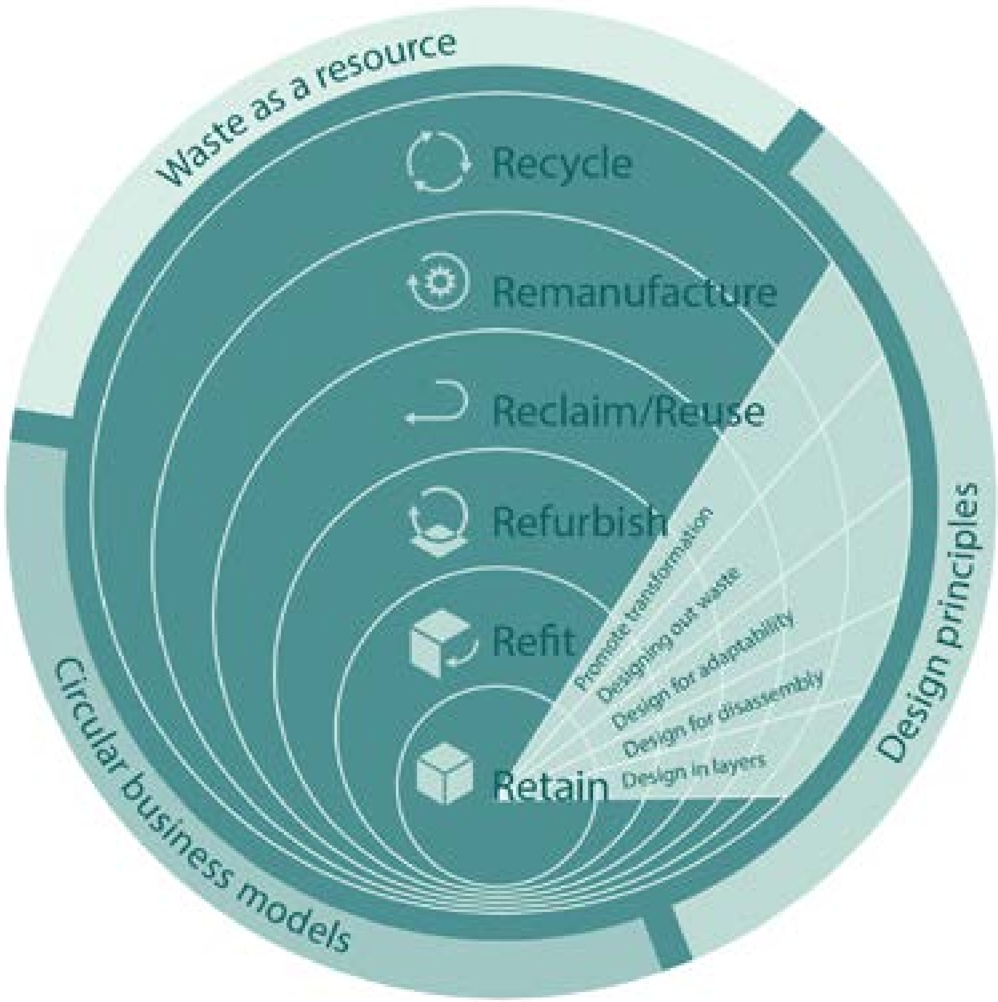
2. It can be done: Real changes are possible by defining a common agenda and applying tools that enable cities to work smarter given the same resources. CIRCuIT has developed tools that can help cities and their stakeholders embed circular economy practices, such as the transformation tool which supports the identification of buildings at risk of demolition, or the dialogue tool which ensures that conversations about circularity start early in the planning process. The CIRCuIT project also developed adaptable procurement requirements in collaboration with the construction industry (see chapter 5). Each of these tools will help to create changes within the landscape, processes, and behaviours.

3. It has scale-up potential: Circular practices are achievable at a building, neighbourhood, city or even country level. To generate the maximum impact of circular construction practices, each of the cities in the CIRCuIT project developed roadmaps that illustrated how best practices could be effectively embedded into city policy (chapters 3 and 5). The project also created working proof of concepts for digital tools such as the Material Reuse Portal that support the delivery of material exchange work and thereby enable increased uptake and the scaling of benefits (see chapter 6).

A call to action

Cities now have the opportunity to connect an ambitious circular economy transition to their sustainability goals. However, to achieve success, cities must also work with professionals from across the entire built environment value chain, from urban planners to material manufacturers, from demolition specialists to residents, and urge them to come together and transform the sector using circular economy principles.

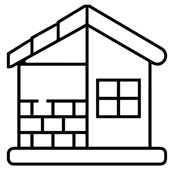
Changing the way that the industry designs, constructs and transforms buildings and infrastructure is critical in the fight against the climate crisis. Thanks to the wide array of tools, case studies and datasets developed by the CIRCuIT project, stakeholders across the value chain are better equipped to turn ideas into reality.



Principles of circular construction
The Handbook to Building a Circular Economy, David Cheshire, AECOM, 2021

Chapter 1: Extending the lives of buildings through transformation and refurbishment

Transformation and refurbishment of existing buildings is the first principle of circular construction. Applying a transformation-first approach will be key to meeting climate targets. Reducing the instances of demolition can keep resources that have already been refined in use for longer, reducing the need for new materials.



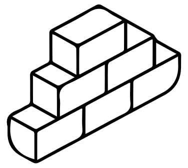
Key findings:

- Methodologies to identify buildings at risk of demolition
- Policy drivers to encourage decision makers and built environment professionals to extend the lives of existing buildings
- 12 demonstrator projects showcasing design transformation strategies.
- 10 business cases for building transformation.

Chapter 2: Increasing the reuse and recycling of building materials

Reusing and recycling building materials is a highly effective way to reduce the resource use and carbon intensity of the built environment by closing material loops. But many challenges are preventing cities from adopting this circular construction approach including issues with cost, adoption and the demolition process.

The CIRCuIT project explored these challenges and suggested ways to embed practical solutions on how cities and the building sector both build and demolish, from policies to Pre-Demolition Audits.



Key findings:

- Recommendations to increase the reuse and recycling of building materials
- Recommendations for embedding pre-demolition audits (PDA) in city policy
- Methodology for developing an optimised PDA
- 12 demonstrators illustrating material reuse and recycling techniques
- 9 business cases for driving the reuse and recycling of building materials.

Chapter 3: Futureproofing cities: designing for disassembly and adaptability

Design for disassembly (DfD) and design for adaptability (DfA) are two construction approaches that can help cities meet their future housing and infrastructure needs while ensuring circular economy principles are adopted. Currently, the technical solutions needed to adopt these approaches exist but take up throughout the construction industry is low. The CIRCuIT project explored what DfD and DfA looks like in practice, how these approaches can be embedded in cities, and how the environmental and economic benefits of DfD and DfA can be calculated to help increase adoption.

Key findings:

- Methodology for assessing the return on investment (ROI) for DfD and DfA across three areas: monetary cost, carbon use and material use
- Methodology to assess whether a DfD or DfA concept is likely to be scaled up across a city
- Roadmaps for DfD and DfA for Copenhagen, Hamburg, London and Vantaa
- 12 DfD and DfA demonstrator projects
- 7 business cases for DfD and DfA approaches.

Chapter 4: Data and indicators for a circular built environment

A consistent and comprehensive approach to data collection, analysis and management is fundamental for a city to accelerate circularity in its built environment. As part of the CIRCuIT project, partners explored the data available in cities, how data capture can be improved and which indicators are key to supporting circularity.

Key findings:

- Two methodologies and template for carrying out a circularity data mapping exercise and assessment of accessible data in a city
- Set of data templates to improve the capture and sharing of data relating to components, spaces, buildings and areas
- Recommendations to help a city address gaps or weaknesses in their data
- Set of 37 indicators that focus on circularity at a city, building and materials level.

Chapter 5: Using policy to power circular construction

Two significant areas where cities can support a transition towards circular construction is through their planning and procurement policies. To help decision makers take effective action in these areas, the CIRCuIT project developed practical guidance on policy interventions, working with developers, criteria for public tenders and city-level circular economy strategies.

Key findings:

- Policy interventions to embed circular approaches in cities
- Checklist to support circular construction dialogue with developers on city projects
- Recommended circular economy criteria for public sector tenders
- Circularity policy roadmaps for Copenhagen, Hamburg, London and Vantaa

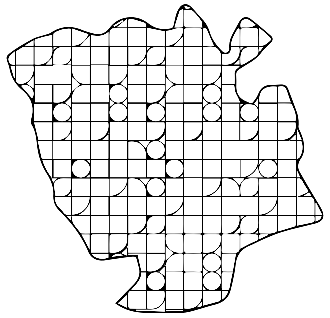
Chapter 6: Supporting circular construction with online tools

If cities are to increasingly transition to circular construction, it's critical that decision makers and built environment professionals have access to tools that can help them turn circular construction theory into practice. As a result, CIRCuIT's project partners developed five online tools to improve professional knowledge, increase acceptance of this way of building and ultimately, accelerate adoption of circular construction.

Key findings:

- Material Reuse Portal
- Circularity Dashboard
- Circularity Atlas
- Citizen Engagement Portal
- Circular Economy Wiki.

Overview of the four CIRCuIT cities

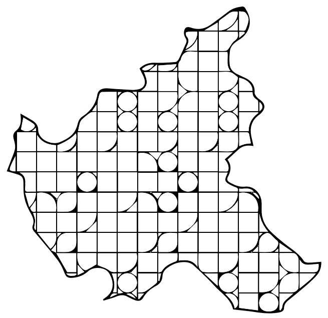


Copenhagen

Copenhagen is internationally renowned for its innovative approach to the climate and the environment. It has a reputation as the world's best city for cyclists. It is a living showcase for Danish architecture. But, most important of all, Copenhagen is a good place to live.

None of this came about by chance. It is the result of years of planning and development based on the needs of Copenhageners – everybody who lives in, uses, visits, works with or runs a business in the city. It is based on the life between the buildings.

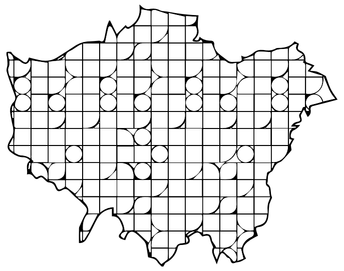
Copenhagen sets ambitious climate goals, aiming to be the world's first carbon neutral capital. It will achieve this through a city-wide transition toward sustainable energy supply, building retrofits, circular waste management, sustainable public infrastructure and mobility, as well as other key initiatives to support the transition.



Hamburg

The Free and Hanseatic City of Hamburg is one of the 16 states of the German federation and the second largest city in Germany. As a member of Eurocities and the City Science Initiative, Hamburg supports European cities and regions, facilitating knowledge sharing across networks, forums and workshops.

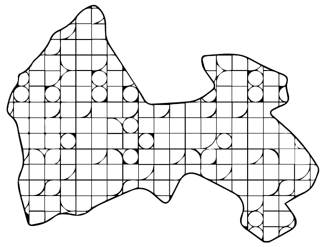
It is currently delivering several EU-funded Interreg and Horizon 2020 projects on urban development, circular economy and smart city elements, harnessing the power of innovation to progress towards its circular goal. In addition, in recent years Hamburg has set up ambitious climate transition targets in line with its industrial composition and socio-economic prospects, and it has introduced sectorial targets, including carbon reduction targets for each sector.



London

London is the engine of the UK economy, accounting for more than a fifth of the country's economic output. Over many centuries London has evolved, resulting in an extraordinary web of distinctive residential streets, squares, markets, parks, offices and industrial and creative spaces.

London aspires to be a zero carbon, zero waste city, and to transition to a low carbon circular economy. This is part of a wider strategy promoting 'Good Growth', which is about working to rebalance development in London towards more genuinely affordable homes, to deliver a more socially integrated and sustainable city.



Vantaa/Helsinki Region

One of three cities in Helsinki metropolitan area, the city of Vantaa is the fourth biggest city in Finland. It has a total area of 240.35 km^2 and a population of 223,000, rising by 2,400 citizens every year. The population is expected to reach over 300,000 by 2050.

Vantaa has a new comprehensive environmental programme called the Roadmap to Resource Wisdom 2030. It focuses on the circular economy and Vantaa's ambition to be carbon neutral by 2030. The circular economy goals consist of reusing materials (including during a demolition), establishing circular economy as part of planning and execution and improving the model for circular economy areas.

Inspiring the reuse and recycling of building materials

The construction industry, and the materials it uses, are responsible for more than a third of global resource consumption. This has significant repercussions on carbon emissions and ecosystem degradation. Reusing and recycling construction materials is an effective way to reduce the resource use and carbon intensity of the built environment.

It was once common to reuse materials in new buildings – but it's now the exception, not the rule. When reused or recycled materials are used, it's usually at a superficial level that doesn't approach the scale necessary to have meaningful climate impacts.

There are many reasons reused materials aren't more widely used. One is the mismatch between supply and demand of reusable and recyclable materials. This means upcoming projects cannot rely on availability of reused or recycled material – which can disrupt timelines. A limited or inconsistent supply means there is no demand for materials at scale.

Another reason is a lack of trust in the quality and reliability of reusable and recyclable materials compared to new. This perception limits their applications and potential for use, with insurance providers often declining to underwrite reused materials. There are real but manageable challenges to overcome around limits in structural applications and potential contamination by hazardous materials.

There's also a lack of standard practice on how to identify and report materials suitable for reuse and recycling. Many contractors are unaware of, or unable to implement, the demolition processes that document and preserve building materials.

A better system is possible

In the face of these challenges, it can be difficult to highlight the potential environmental and economic benefits of using reused and recycled materials. Without consistent and standardised reporting, measuring cost and carbon footprint benefits is a costly exercise in itself.

Improving this system is possible. Urban mining means recovering and reusing cities' building materials – high-quality reusable and recyclable materials can be extracted from existing buildings if the right demolition techniques are used. This can play a key role in helping built environment stakeholders reduce their environmental impact, costs and waste.

A secondary material reuse market can be created by applying standardised documentation, using digital and physical infrastructure, establishing behaviour change mechanisms and sharing case studies highlighting benefits – as well as supporting city-wide policies.

This chapter looks at practical steps to achieve these goals. It reviews CIRCuIT's findings on pre-demolition audits supporting city-level policies, shares practical demonstrators and business cases that can be taken from them.

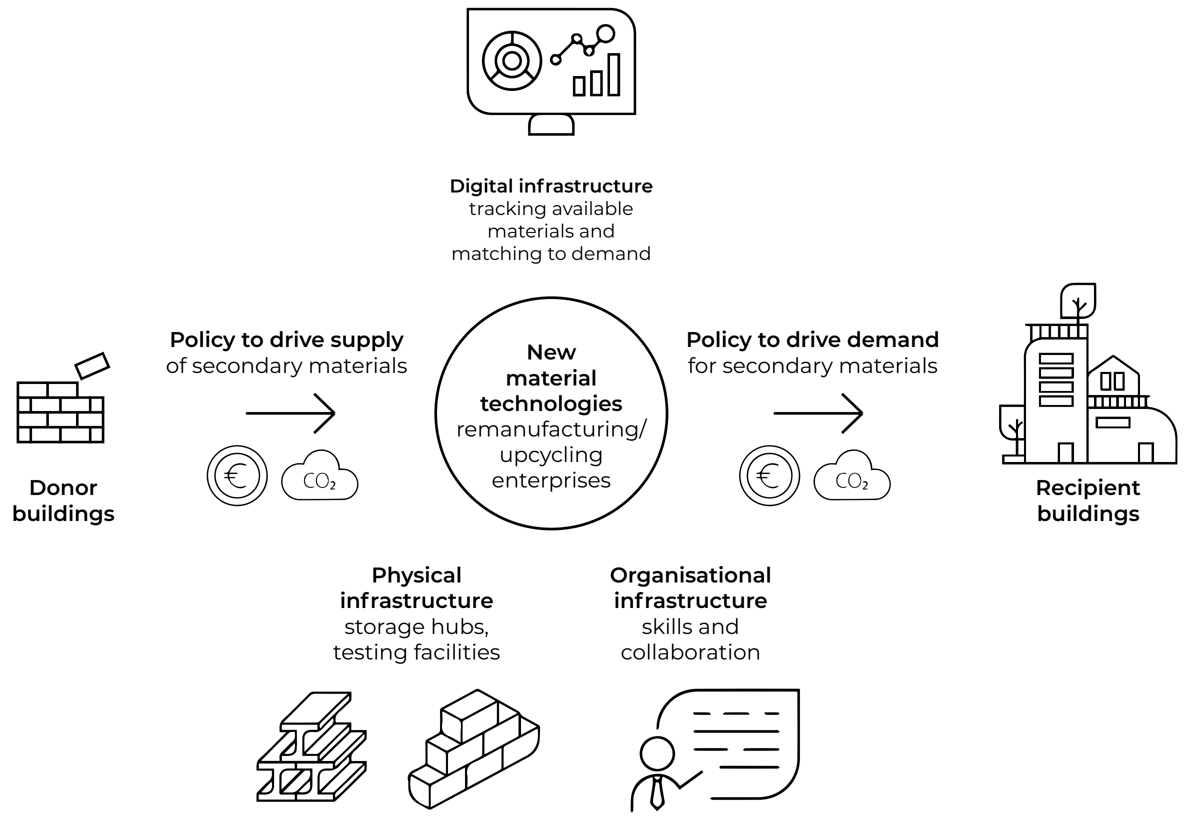


Figure 2.1: Material Reuse Landscape

Urban mining in action – examples of material reuse and recycling

Working with each other and local built environment stakeholders, partner organisations in the four CIRCuIT cities developed and evaluated 12 demonstrator projects to showcase urban mining strategies and the benefits they can deliver. Four are showcased here.

Below is an overview of each project, the techniques used and key learnings.

Full overviews including detailed carbon and cost assessments of all demonstrators can be found at circuit-project.eu/post/latest-circuitreports-and-publications

Copenhagen

Gladsaxe school / The Swan - Selective disassembly

Physical Demonstrator

Overview

The Gladsaxe school is an interesting case for PDA assessment because it represented two types of buildings – it was built in 1937 and extended in 1967.

Materials from the school were used to construct a new kindergarten on the same site, making it easier to plan for urban mining (see page 2-10). This included wood recovered from demolition in the kindergarten's entry hall, wooden trusses, steel sheets, pantiles, masonry and specific fixtures and accessories such as lamps and sinks.

Reuse of the wooden trusses was the main focus of the project, with six forming the load-bearing roofing elements in the new kindergarten's entrance hall.

Nearly 6,000 tonnes of concrete were also crushed and used for the kindergarten's foundations and site backfilling.

Key actions taken

The pre-demolition audit involved an interdisciplinary team, with stakeholders from the entire construction value chain. Timber rafters from the roof were carefully cut free according to predefined and agreed cutting lines. Three types of steel cladding were dismantled from the building and bricks were taken down using a Cat digger and cleaned manually from mortar. Roofing tiles were also selectively dismantled from the school.

Key findings

The pre-demolition audit of a building should be a process that involves stakeholders from the entire construction value chain to ensure the highest possible level of recycling and reuse. In particular, the demolisher of the existing building and the architect/developer of the new building should go through the existing building together to discuss and agree on reusable/recyclable items.

It's crucial to use expert reuse consultants for the initial building mapping who can steer cross-disciplinary processes so circular practices are used rather than linear approaches. An open house at the demolition site, a virtual open house or a digital model, could be used early on to connect built environment stakeholders with each other. They can then explore how they would work together to reuse or recycle materials from the existing building.

Storage of extracted materials should be a consideration. For example, the timber extracted from the Gladsaxe school needed to be stored in a place where it was covered and ventilated, so it didn't rot.

If a developer includes the reuse of building materials in their tender, it will be calculated in project finances from the beginning. That means it's less likely to be overruled later in a project due to economic or practical reasons.

If building materials are initially regarded as reusable products rather than waste, regulations may state they don't have to be checked for hazardous substances. As a result, it's important that an initial screening for hazardous substances takes place along with the PDA to ensure materials that could harm the environment or people don't remain in the built environment.

Reusing timber is an opportunity to extend the carbon storage of wood. Growing trees store carbon, which is then released when wood is burned. However, assessing wood for reuse is relatively simple, if standards are followed. Reusable wood may be deformed or crooked, which should be considered when designing a new building.

Hamburg

Die Musterbude – Testing the performance of recycled concrete mixtures

Physical Demonstrator

Overview

Die Musterbude is an innovative project that involves the construction of a small cabin using seven types of recycled concrete. Recycled concrete has been used for decades – but this project tested new mixes featuring materials like recycled sand and waste materials from demolished buildings against conventional concrete. The project aimed to assess the technical and environmental qualities of the recycled concrete mixtures against a standard concrete mixture that uses new aggregates.

The recycled concrete, which is derived from crushing and reusing excess concrete from demolished structures, is the primary construction material for the Musterbude.

The project allows a deeper understanding of how recycled concrete performs in real-world applications and its potential benefits in terms of sustainability and material circularity.

By demonstrating the successful use of recycled concrete aggregates, the project sets a compelling case for sustainable construction practices that advance the circular economy in construction.

Key actions taken

The project produced various aggregates from construction and demolition waste. They were tested for optimal screening and washing both in the lab and in the finished construction. Out of this process, seven new recycled concrete recipes were developed. Life cycle assessment and costing was carried out.

Key findings

The project team found mixtures with a higher percentage of recycled concrete have a lower environmental impact. However, mixtures with a higher percentage of recycled concrete lead to more water consumption because of the porosity of recycled aggregate. The amount of water could be reduced by using polycarboxylate superplasticizers (PCEs) in the concrete mix (a chemical admixture) and pre-washing aggregates.

The Hamburger Mische mixture, which contains 100% mixed construction and demolition waste, achieved good concrete strength and surpassed expectations.

Because of these positive results, the mix will be further improved and used locally in Hamburg

Vantaa/Helsinki region

Tikkurila school warehouse – Reusing red clay bricks

Physical Demonstrator

Overview

Reclaimed red clay bricks, including from the National Theatre of Finland, were reused to construct a small storage building in the yard of the Tikkurila Pavilion School. Bricks were identified as a prevalent and reusable building material in the pre-demolition audits of two demolition cases in Vantaa.

The aim of the demonstrator project was to develop cost-effective methods to investigate the quality of deconstructed bricks (and potentially other materials). It was also to assess the environmental and economic performance of reused bricks against virgin bricks.

Key actions taken

Bricks were deconstructed with hand-held power tools and an excavator. An assessment was carried out between material properties acquired with indirect (non-destructive) methods and those acquired with direct (destructive) methods. There was also an assessment of the environmental and economic performance of reused bricks in comparison to virgin bricks. Recommendations were noted about appropriate methods and sample sizes. Ultimately, reclaimed bricks were used to build the storage building.

Key findings

Indirect methods to study the material properties of reclaimed bricks include assessing the colour of a brick and its pitch when struck to sort into different categories. Compression strength and freeze-thaw durability of a reclaimed brick can be evaluated with ultrasonic pulse velocity. Both are rapid, low-expense tests that can be performed at a demolition site. This contributes to the cost-effectiveness of the reuse process. However, only laboratory tests can determine compression strength and freeze-thaw resistance accurately.

Reused bricks must be selected carefully for the right area of a building to ensure an 'attractive' side of the brick is visible. This selection takes more time than using new bricks.

London

Glulam from secondary timber

Physical Demonstrator

Overview

The London demonstrator investigated the technical and logistical feasibility of upcycling reclaimed timber into new building components.

This involved retrieving timber from demolition sites, characterising and quality-testing the material, preparing it for manufacture and fabricating new glued-laminated timber building components.

Key actions taken

Timber was reclaimed from building demolition sites. The reclaimed timber was characterised, visually and mechanically, to prepare it for the manufacturer. New laminated timber building components were manufactured from reclaimed timber.

Bending tests and shear tests were carried out on the glulam beams. Test results were compared with benchmark results of glulam fabricated from virgin timber. Finally, recommendations were provided on deconstruction, regrading and manufacture in relation to secondary timber laminated building components.

Key findings

There was good correlation between non-destructive and destructive testing of the stiffness of manufactured secondary timber glulam beams. As stiffness is a good indicator of strength, this suggests that secondary timber glulam beams could be commercially tested using non-destructive methods (as is the case with virgin glulam products) to verify product performance.

The glulam beams made of secondary timbers performed to structural glulam standards.

No additional time is needed for removal of timber compared to business-as-usual demolition practices. If it takes no longer to remove the timber then there isn't a cost premium on accessing the material.

Identification and removal of screws, nails and staples is crucial to avoid damaging the tools used in the glulam manufacturing process.

Longer secondary timber lengths, ideally 1.5m or longer, enable a cost-effective manufacturing process by minimising the number of finger joints required.

Optimising the pre-demolition audit

Pre-demolition audits (PDAs) are critical to driving recycling and reuse in construction.

Why PDAs?

A PDA is a comprehensive and systematic assessment of the quantity and quality of elements and materials left after a building's demolition. It can be used as a tool to identify potentially reusable and recyclable components. When completed well ahead of demolition this information can be fed into a digital platform where professionals can see what materials will become available for upcoming designs.

Implementing PDAs in policy

Currently, PDAs are not required as part of the demolition process in most cities.

Where they are required or encouraged, they are often not compulsory, standardised or set up to support circularity. Existing policies and demolition auditing methodologies also typically focus on hazardous materials and their waste codes. This frames outgoing materials as waste rather than usable resources. Even when detailed information is collected, it's not standardised. This doesn't allow for the aggregation necessary to share material information at scale. Making sure planning policy requires PDAs in a standardised format would overcome these challenges.

Recommendations to successfully embed PDAs in city policy

Establish digital system to capture PDA data

Ensure city planning data systems can capture the material data included in PDAs. This will allow the collected data to be used to support secondary material reuse.

Standardise PDA format and guidelines

Align PDA reporting with local best practice, in discussion with industry, to ensure data can be transferable.

Make PDAs mandatory

Once a digital system can actively use and support PDA submissions, the PDA should be made mandatory. Efforts should be made to give the PDA a legal basis and make it part of a corresponding law. The current voluntary nature of the PDA does not create incentives for increased use. Due to the country-specific legislation in the construction sector there isn't an EU-wide consistent way of integrating the PDA into legislation. Accordingly, it cannot be recommended to make the PDA mandatory on a European level. Instead, it is recommended to make the PDA mandatory at the national or local level.

Expand PDAs to include pre-redevelopment audits

To fully capture all the potential material flows in the city, PDAs should also be carried out for retrofit or renovation projects.

Frame PDAs as part of the building life cycle

Rather than viewing the PDA as a standalone procedure dealing with 'waste' it is recommended to integrate it into the building life cycle. It is recommended to perform the PDA as early as possible and to frame the identified materials as resources. Doing this will enable long-term planning processes and more transparency in intended handling of building stock.

Make PDAs more understandable and intuitive

The title 'Pre-demolition audit' can be unnecessarily confusing for some people. Changing it to something like 'Urban mining audit' or 'Circular material audit' could help spread awareness.

Update PDA tools

The tools used to complete the audits should also be updated to be more intuitive and user-friendly than the current Excel models.

Make PDA information accessible to all stakeholders

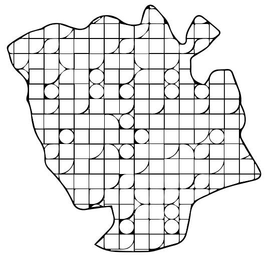
To capitalize on all the benefits of completing PDAs, the data must be accessible to the industry at large: collectively they provide a database of building components that will soon become available.

Incorporate the PDA steps into contracting

For public tenders: Perform the first step of the PDA: element and material assessment before issuing the tender and use it to make a detailed performance description. The demolition contractor will then respond with the second step of the PDA: management options as part of the offer. The contract will make the procedure legally binding.

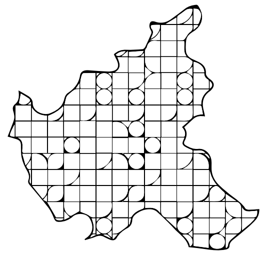
How cities are embedding pre-demolition audits

Though not formally required, the CIRCuIT project cities have already implemented PDAs in some policies to varying degrees. The range of approaches illustrates the various ways cities can embed PDAs into current practices.



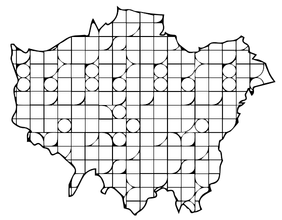
Copenhagen

For most projects, hazardous waste screening is already mandatory in Denmark, while PDAs mapping material quantities and quality is voluntary. The city has made PDAs mandatory for their own projects. Work is being done to create a national standard for both environmental mapping and PDAs. This includes standardising reporting and a basic training programme that is required so that only trained auditors can have their work approved. In the meantime, the municipality is working on creating a standard procedure for PDAs in owned buildings in which a digital platform can handle all the steps and gather data in one place.



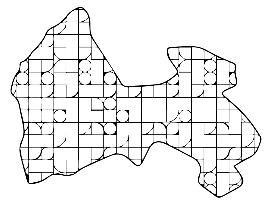
Hamburg

PDAs are not yet required or recommended in Hamburg, but there are requirements for hazardous waste screening and separation. Demolitions are often completed on short notice. This means there's limited time to realise the benefits of PDAs. The City of Hamburg is examining if they can make a digital PDA available as an open data source through the city's website for construction projects. At the same time, future integration of PDAs in public tenders is being discussed.



London

PDAs are not the norm in London. However, in recent years there has been an increase in their use on larger developments. Most PDAs are completed to earn Building Research Establishment Environmental Assessment Method (BREEAM) credit or to fulfil Circular Economy Statement (CES) requirements. These were introduced in 2020 and came into effect in 2021. Policy on PDAs will most likely continue to be addressed through the CES policy at city and borough level.



Vantaa

PDAs are currently conducted in all demolition projects owned by the city of Vantaa. To support developing demolition data collection in the current registers of the city, Vantaa has joined the national Green Deal on sustainable demolition, which requires systematic use of PDAs. The Green Deal is with the Ministry of the Environment and sustainable demolition agreements are valid until 2025. PDAs are currently voluntary in Finland. The new and reformed Building Act will come into effect at the beginning of 2025. It will oblige a waste and demolition material estimate before a demolition permit can be granted, and a waste and material statement after the demolition has been finalised.

Developing an optimised pre-demolition audit

The CIRCuIT project developed an easy-to-understand methodology, template and checklist to support built environment stakeholders to carry out PDAs and increase material circularity in their local area.

These outputs were tested in 12 demolition demonstrator projects: three each in Copenhagen, Hamburg and London (Please see page 2-4 for more information).

Pre-demolition audit methodology

Follow these steps when using the PDA template and checklist developed by CIRCuIT partners.

Step 1 – Desk study
Analyse relevant documents to collect information about the building's history. The age of building and/or past works are essential information and related to the presence of hazardous materials such as asbestos or heavy metal-contaminated materials. Carry out initial inventory of materials.

Step 2 – Field survey
The auditor should visually inspect all parts of the site to be demolished. This phase is important to verify quantities of materials, evaluate their condition and potential for reuse, and estimate the amount of waste from demolition. Inventory of materials is completed with the field survey.

Step 3 – Inventory completion
The inventory happens during the desk study and field survey. It includes the type and quantification of reusable and recyclable materials and components, as well as hazardous materials and eventual waste fractions. Record through photos, comments or advanced scanning approaches that allow a faster execution of the audit and easier interpretation.

Step 4 – Recommendations
The audit provides recommendations on how to:

- preserve valuable components and materials during the demolition activities
- safely remove hazardous and/or waste fractions
- manage waste logistics and operations.

Step 5 – Report
The report must include information on the project, the information collected during the desk study and field survey, and any information that can be useful for the owner, contractor or any other stakeholder involved.

Pre-demolition audit template

The optimised PDA template developed as part of the CIRCuIT project is available to download at circuit-project.eu/post/latest-circuit-reportsand-publications

Recommendations to increase reuse and recycling of building materials

Digitize planning process and allow open access to data

Improved material data transparency and material information improves market confidence, reduces risk and provides opportunities for long-term planning. Improved material information should facilitate improved quality assurance and consumer material choice to compete with virgin construction materials and enable more opportunities for closed loop reuse and recycling of materials.

Relevant stakeholder(s)

Public stakeholder(s)

Establish materials exchange platforms for city and/or region

Material exchange platforms provide the data infrastructure necessary to facilitate material exchanges showing the material supply and demand.

Relevant stakeholder(s)

Building industry

Connect data collected during planning with material exchange platforms

To take advantage of the high-quality data collected during the planning process, connect this data with material exchange platforms where possible. This will allow information coming from planning requirements, such as the PDAs, to be used practically on existing networks without delay.

Relevant stakeholder(s)

Public stakeholder(s)

Develop alternative quality assurance methods

Develop alternative non-destructive methods for quality assurance of reused materials

Relevant stakeholder(s)

Building industry

Develop alternative funding options for pilot projects

Provide alternative funding schemes for ambitious circular projects in public building projects to meet increased up-front costs related to innovative secondary material use.

Relevant stakeholder(s)

Public stakeholder(s)

Temporary urban storage facilities

Establish temporary storage facilities for reuse materials from private or public demolishing sites.

Relevant stakeholder(s)

Building industry | Private stakeholder(s) | Public stakeholder(s)

Standardised secondary materials

Pursue and develop standardised secondary building materials and components for large-scale market uptake.

Relevant stakeholder(s)

Building industry | Public stakeholder(s)

Establish training on improved selective demolition

There is room for improvement in selective demolition technologies and workforce skills. Lack of industry knowledge and/or experience on damage-free disassembly leads to degradation of materials which severely reduces circular opportunities. Skilled and experienced contractors to guide circular processes are crucial.

Relevant stakeholder(s)

Building industry | Public stakeholder(s)

Promote and educate on material reuse and recycling

Addressing lack of knowledge about the value and benefits of material reuse and recycling requires awareness and educational initiatives. Industry associations, government agencies and construction companies can collaborate to raise awareness about the environmental advantages, cost savings and sustainability benefits. This can be achieved through workshops, seminars, training programmes and information campaigns highlighting successful case studies and showcasing the positive impact of material reuse and recycling.

Relevant stakeholder(s)

Building industry | Public stakeholder(s)

Develop alternative disassembly practices

Time-consuming manual handling is often required for the high precision tasks of removal and cleaning building elements and components. Innovative technology and equipment is needed to reduce labour-intensive practices.

Relevant stakeholder(s)

Building industry

Making the case for reusable and recyclable building materials

A 'business case' makes the case for change. It is directed at a specific audience who can make the proposed change and describes actions to be taken outside of BAU and expected outcomes. Four of the business cases that were developed drawing on the carbon and cost analysis of the CIRCuIT urban mining demonstrators projects, are shared here.

Each business case includes five perspectives presented under the headings: strategic, financial, feasibility, risk and scalability. Together these commentaries and the demonstrator templates provide evidence on the benefit of investment in the proposed changes for both the decision maker and the community.

> **A full list of all business cases developed from demonstrator results can be found in appendix A1.2**

A. Public and private asset owners can assess cost and carbon saving opportunities from reuse across projects and asset portfolio by commissioning and acting on pre-demolition audits.

Strategic: Public and private asset owners can identify opportunities to make cost and carbon savings through reuse of materials across projects and assets in their portfolio. They can achieve this by commissioning PDAs in the early design stages of major redevelopment and building upgrades.

Financial: The cost of commissioning a PDA is small in the context of construction costs. One demonstrator found a 12% saving in construction costs through on-site use of recycled aggregates. A demonstrator comparing deconstruction and component resale to demolition and scrap value of a structural steel frame found that the cost premium involved in deconstruction is £50/tonne and additional resale value is £80/tonne. However, if it is assumed that 20% of the deconstructed steel is lost to cutting, the deconstruction option becomes 8% more expensive than BAU. A demonstrator reusing timber trusses on site also reported increased costs, largely due to additional handling, processing and fitting costs compared to BAU. A demonstrator comparing reclamation of bricks laid in cement mortar using hand-held power tools and an excavator found that using hand-held tools produced reusable bricks at a higher cost than other reclaimed bricks on the market. However, using an excavator produced reusable bricks that were cheaper than other reclaimed bricks (by 48%) and cheaper than virgin bricks (by 24%).

Feasibility: There is increasing familiarity with PDAs in industry and capacity for carrying them out in early design stages, in line with CIRCuIT recommendations. However, many secondary material supply chains remain in their infancy and do not have the economies of scale enjoyed by conventional supply chains.

Risk: CIRCuIT policy recommendations include making PDAs mandatory for all projects or all government projects. Building this into procedures now, demonstrates leadership from local authorities and enables forward-thinking developers to stay ahead of legislation.

Scalability: The potential impact of PDAs increases as more are carried out. With more reusable materials identified and made available through digital platforms, data collection will reach a tipping point where it becomes a fertile place for specifiers and procurers to source materials they need. That scale will reduce the costs of deconstruction, processing and testing. Across a portfolio, there may be timely opportunities to direct components from one project to another. Local authorities can also offer materials at low cost to projects that achieve other goals such as social value. In the medium term, aggregated findings from PDAs provide data that can be used to support future policymaking. Innovative surveying methods could improve the quality of information generated and/or reduce the cost of PDAs.

Related demonstrators: Demonstrator 2 – Offakamp, Demonstrator 4 – Gladsaxe School / The Swan, Demonstrator 6 – Hyltebjerg skole, Demonstrator 7 – Hevoshaka school, Demonstrator 8 – Vantaankoski school, Demonstrator 10 – Component reuse of retail unit, Demonstrator 11 – Leadenhall

G. Local authorities can help to create circular supply chains by driving demand for novel remanufactured secondary materials and adopting their use in public projects.

Strategic: Local authorities can reduce embodied carbon emissions in line with their own carbon reduction objectives by taking a leading role in briefing design teams to specify secondary materials. This will also help break down barriers to wider adoption of novel materials.

Financial: New remanufacturing initiatives may not be able to deliver like-for-like materials cost neutrally when compared to existing manufacturers that operate with significant economies of scale. In the demonstrator project on which this case is based, the time involved in deconstructing timber framing was estimated in general to add 15% to the demolition contractors' costs. This would lead to more expensive feedstock for glulam production than using primary timber as usual. However, there is a holistic economic benefit to the area if more construction spend is retained in the local economy. This spend also helps new businesses expand and reduces their costs, increasing the competitiveness of circular supply chains in the longer term.

Feasibility: Adopting novel materials requires strong impetus from those commissioning construction to set a 'direction of travel'. Officers in development and regeneration roles will need to understand the reasons for the policy and act as custodians as it is enacted in briefs and challenged through the course of a project's development. Appointed design teams will be asked to specify materials in a way that differs from their normal practice. Likewise, contractors will be asked to build with materials that may vary from those they are familiar with. Clarity of rationale and awareness of carbon and circularity will be key to resisting pressure to revert to BAU.

Risk: Association with innovative, circular businesses can enhance the reputation of a local authority among staff, residents and industry. The opportunity cost of achieving carbon savings or other environmental benefits should be weighed against other options for achieving the same benefits. The starting point is to understand the scale of benefits. In the demonstrator case, using secondary timber in glulam manufacture was found to achieve a 40% reduction in embodied carbon (cradle-to-gate), and almost a 200% increase in the biogenic carbon stored in wood (grave-to-cradle-to-gate).

Scalability: The ability to scale this business case depends on availability of novel secondary materials ready to be supplied to major projects. The emergence of these supply chains can be supported by developing physical and digital infrastructure that creates a more effective market for secondary materials. It should also make available materials more visible and reachable by remanufacturing businesses. Organisational infrastructure will develop workforce skills and capacities for deconstruction, testing and recertification and form links in supply chains. Greater demand for secondary materials from across the market, driven by progressive purchasing, tighter regulation of whole life carbon or carbon pricing will create more opportunities for new circular businesses.

Related demonstrators: Demonstrator 12 – Glulam from secondary timber

P. Local authorities can help to create supply chains for secondary materials by establishing circular economy construction hubs closer to city centres.

Strategic: Local authorities can reduce embodied carbon emissions of their own buildings, and other developments under their jurisdiction, by allocating sites for circular economy construction hubs and facilitating partnerships to establish and manage them.

Financial: Circular economy construction hubs improve the likelihood of retaining value from materials in the local economy. This can reduce the length of supply chains, minimising exporting waste and importing materials, and increasing local employment. Reuse opportunities are sometimes missed due to lack of available space to store materials or inflated costs because materials need to be taken to remote storage.

Investigating potentially reusable materials was found to be a time-consuming exercise that requires significant effort from the design team. In one demonstrator this accounted for around 10% of the total cost involved with reusing glulam beams (although total costs were 12% less than new glulam). As the reuse process becomes more visible in cities through hubs, and more familiar to teams, the transaction costs involved with new ways of sourcing materials will come down.

Feasibility: Leveraging existing skills, capacity and experience through partnerships with organisations already involved in managing related sites will be key to establishing them. This could include demolition contractors, reclamation yards, builders' merchants, construction consolidation logistics centres, developers, universities and colleges and production facilities.

Risk: Temporarily using disused brownfield sites earmarked for long-term redevelopment may provide opportunities to road-test circular economy construction hubs. This can activate sites that are otherwise providing no social value and detracting from the urban environment.

Scalability: This case can be seen as a step in evolving urban waste management infrastructure to circular economy infrastructure. Policy targets for net waste self-sufficiency (e.g. the London Plan policy of the equivalent of 100% of London's waste being managed within the city by 2026) should be established to support development of such sites. In the demonstrator projects on which this case is based, local recirculation of materials achieved carbon emissions reductions of 2-6%, 8%, 40% and 47%.

Related demonstrators: Demonstrator 1 – Luruper Hauptstraße, Demonstrator 3 – Musterbude, Demonstrator 5 – Stablen / The Stack, Demonstrator 12 – Glulam from secondary timber.

U. Demolition contractors can achieve new revenue streams by becoming retailers of recovered materials.

Strategic: Demolition contractors can rebrand as urban mining specialists and open up new revenue streams by recovering more materials and finding markets for their reuse, remanufacturing or high-quality recycling.

Financial: Demolition contractors already seek to minimise disposal costs by identifying materials that can be sold by reclamation yards. But this is usually limited to high-value goods for heritage projects. There is growing demand for other secondary materials, such as structural steel. In one demonstrator project on which this case is based, the time involved in deconstructing a steel frame was estimated to add £50/tonne – but additional resale value is currently around £80/tonne. If it's assumed that 20% of the deconstructed steel is lost to cutting, the deconstruction option becomes 8% more expensive than typical demolition and scrappage. For brick laid in cement mortar, a demonstrator found that costs were heavily dependent on the deconstruction method. Using an excavator, despite breaking more bricks, produced reusable bricks at a cost 48% lower than other reclaimed bricks on the market, and 24% lower than virgin bricks.

Feasibility: Improving skills and technology will simplify deconstruction and reduce time and cost. Greater familiarity with markets for secondary materials will simplify identification of materials that can be resold and reduce transaction costs.

Risk: Shifting from demolition to deconstruction and urban mining minimises businesses' exposure to the risk of demolition becoming an unacceptable approach in many contexts. Supplying materials directly to other construction projects may require the development of testing procedures and warrantying. Demolition contractors could integrate these operations or supply to specialists who prepare products for resale.

Scalability: Greater demand for secondary materials from across the market, driven by progressive purchasing and tighter regulation of whole life carbon or carbon pricing, will increase margins between deconstruction costs and resale prices. This will allow more material types to be profitably recovered.

Related demonstrators: Demonstrator 5 – Stablen / The Stack, Demonstrator 8 – Vantaankoski school, Demonstrator 9 – Tikkurila School Warehouse, Demonstrator 10 – Component reuse of retail unit.

Further reading

For further information about these outputs and the work behind them, please read the following reports, which were published by members of CIRCuIT partner organisations during the lifetime of the project.

- D4.1 Documentation with audit result, inventory and demolition guide for execution
- D4.2 Achieved reuse, refurbishment and recycling quota energy and resource balances and cost analyses for the demonstrator cases
- D4.3 Recommendation for improving the use of recycled materials and reusable elements

All these reports can be downloaded at circuit-project.eu/post/latest-circuit-reports-and-publications

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Gareth Owen Lloyd, Clear Village

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CIRCUIT

A

Appendices

A1.1: CIRCuIT demonstrators

	Theme	City	Demonstrator name
1	Urban Mining	Hamburg	Luruper Hauptstraße
2	Urban Mining	Hamburg	Offakamp
3	Urban Mining	Hamburg	Musterbude
4	Urban Mining	Copenhagen	Circulation of materials from Gladsaxe school / The Swan
5	Urban Mining	Copenhagen	Stablen / The Stack
6	Urban Mining	Copenhagen	Hyltebjerg school
7	Urban Mining	Vantaa/Helsinki Region	Hevoshaka school
8	Urban Mining	Vantaa/Helsinki Region	Vantaankoski school
9	Urban Mining	Vantaa/Helsinki Region	Tikkurila school warehouse
10	Urban Mining	London	Component reuse of retail unit
11	Urban Mining	London	Demolition of One Leadenhall Street
12	Urban Mining	London	Glulam from secondary timber
13	Transformation	Hamburg	Godewind Park
14	Transformation	Hamburg	Horner Geest
15	Transformation	Hamburg	Gröninger Hof Parkhaus
16	Transformation	Copenhagen	1900s housing urban densification
17	Transformation	Copenhagen	1970s housing estate – Taastrupgård
18	Transformation	Copenhagen	1930s commercial plot
19	Transformation	Vantaa/Helsinki Region	Korso school
20	Transformation	Vantaa/Helsinki Region	Transforming 1970s public rental housing
21	Transformation	Vantaa/Helsinki Region	Adaptive reuse of office buildings for housing in Vantaa
22	Transformation	London	Extending the life of a large 1980s commercial shopping outlet
23	Transformation	London	Transformation of Meridian Water Block F
24	Transformation	London	Transformation of 31-34 North Row
25	Dfd and Dfa	Hamburg	Hamburger Klassenhäuser – Slab construction
26	Dfd and Dfa	Hamburg	Hamburger Klassenhäuser – Façade comparison
27	Dfd and Dfa	Hamburg	Neustadt – Partition walls
28	Dfd and Dfa	Copenhagen	Copenhagen Adaptable housing
29	Dfd and Dfa	Copenhagen	DfD modular façade – Taastrupgård
30	Dfd and Dfa	Copenhagen	Living places Copenhagen
31	Dfd and Dfa	Vantaa/Helsinki Region	Vantaa Hybrid school
32	Dfd and Dfa	Vantaa/Helsinki Region	DfD Warehouse
33	Dfd and Dfa	Vantaa/Helsinki Region	Helsinki Adaptable flats
34	Dfd and Dfa	London	Albion Street / The Hithe
35	Dfd and Dfa	London	Meridian Water: RightSizer
36	Dfd and Dfa	London	Green Street Workspace, Newham

A1.2: Business cases emerging from the CIRCuIT demonstrators

A 'business case template' was prepared based on data attributes and analytics developed during the CIRCuIT project to support, monitor, measure and assess CIRCuIT demonstrator projects.

This template has been used as the framework to gather data and present findings from demonstrators across the three core themes of the project: urban mining and material reuse, building transformation and life cycle extension, design for disassembly and adaptability. The completed templates for all demonstrators can be found at circuit-project.eu/post/latest-circuit-reports-and-publications.

In this section, cases emerging from all demonstrators are aggregated to provide a selection of concise, evidenced, and actionable business cases. A 'business case' is understood as making a case for changing something. It is directed at a specific audience who can enact the proposed change. It describes actions to be taken outside of BAU and the outcomes that are expected. These commentaries and the demonstrator templates provide evidence on the benefit of investment in the proposed changes for both the decision maker and the community.

Public and private asset owners, investors, and developers

A. Public and private asset owners can assess cost and carbon saving opportunities from reuse across projects and asset portfolio by commissioning and acting upon pre-demolition audits

Related demonstrators: 2 – Offakamp, 4 – Circulation of materials from Gladsaxe School / The Swan, 6 – Hyltebjerg School, 7 – Hevoshaka School, 8 – Vantaankoski school, 10 – Component reuse of retail unit, 11 – Demolition of One Leadenhall Street

Public and private asset owners can reduce costs and carbon emissions by implementing PDAs proactively or in early project stages. By understanding the materials available for reuse and establishing a potential material reuse pipeline, materials more likely to be exchange within the asset portfolio. Financially, conducting PDAs early can offer a cost- material solution. One demonstrator found a 12% construction cost reduction by implementing onsite use of recycled aggregates. While PDAs are gaining industry familiarity, some secondary material supply chains do not have the financial capacity yet to widely and strategically implement them. Policy recommendations suggest mandating PDAs for all projects, upscaling PDAs and in turn reducing the costs of deconstruction, processing and testing.

B. Public and private asset owners can identify the optimum cost and carbon approach to projects by commissioning assessments of different degrees of retaining and transforming existing assets

Related demonstrators: 19 – Korso School, 24 – Transformation of 31-34 North Row

Owners of public and private assets can identify optimum cost and carbon approaches to projects by commissioning early-stage assessments of the different ways to use buildings (I.e transformation and retention). The demonstrator projects have shown that optimal retention approaches (achieved through early assessments) can save 7% - 41% of total project costs, amounting to €1 million - €5.5 million saved making a strong case for investing in these assessments. The skills and knowledge do exist to implement assessments to retain buildings and in turn reduce costs and associated carbon. It is vital to consider the cost and carbon saving benefits with evidence at the beginning of projects and appoint experienced consultants. For less economically viable projects, financial incentives such as (in a UK context) charging VAT equally on new build and refurbishment might be necessary.

C. Public and private asset owners can assess existing housing roof and loft spaces and other opportunities for densification

Related demonstrators: 16 – 1900s housing urban densification, 20 – Transforming 1970s public rental housing

Public and private asset owners can assess existing housing roof and loft spaces and other opportunities for densification to cope with increasing housing demand. This essentially means accessing the benefits of transforming roof spaces into residential space. For example, demonstrator project 16 assessed several roof transformation projects in Copenhagen to conclude that roof transformations for residential space can enhance environmental performance, in turn supporting the case for transformation. Roof conversions for housing is technically straightforward but they have legislative and financial obstacles which limits the upscaling potentially, however more assessments of the benefits could help to build a case for more lenient roof conversion regulations.

D. Public and private asset owners can activate a neighbourhood and support new businesses by retaining existing assets for meanwhile use during long-term, phased regeneration projects.

Related demonstrators: 23 – Transformation of Meridian Water Block F

Public and private asset owners can activate a neighbourhood and support new businesses and job creation by assessing masterplans to identify existing assets to retain for temporary use during long-term, phased regeneration projects. In the demonstrator project, construction costs for adapting an existing building were 6% less than providing an equivalent new building. The projected return on investment over a fifteen-year temporary use period was enhanced by 8% compared to the new build alternative. Building retention option creates significantly higher net revenue, more jobs and a greater net total Gross Value Added when compared to when an existing building is demolished, not replaced, and the land is rented out. Building retention for temporary use is technologically feasible, but the challenge lies in recognising opportunities early and prioritising benefits in planning. With long redevelopment timeframes, there is good scope to treat existing buildings as assets that can provide income and social benefits through temporary use.

E. Public and private developers can create more valuable homes, improve resident satisfaction and reduce life cycle cost by developing adaptable housing

Related demonstrators: 28 – Copenhagen adaptable housing, 30 – Living places Copenhagen 33 – Helsinki adaptable flats, 35 – Meridian Water: Rightsizer

Public and private developers can create more valuable homes, improve resident satisfaction, and reduce lifecycle cost by creating adaptable housing. In the CIRCuIT demonstrators the upfront costs for adaptable housing were 21% - 24% higher. However, in one case life cycle cost savings of 28% were achieved if the spaces was adapted compared to demolishing and rebuilding after one use cycle. Adaptability of the spaces was made possible through simple design changes using available construction methods. Resident surveys show demand for adaptable flats, with a willingness to pay a premium (2–10%) for the communicated benefits. In homes owned by residents, a noted challenge was making owners aware of potential savings to motivate them to invest in adaptability. For public developers and housing associations, it's crucial to use life cycle costing over multiple life cycles to evaluate the benefits of designing for adaptability when they retain ownership.

F. Public and private landowners and asset owners can achieve increased rental income by facilitating meanwhile use of underused land and assets.
Related demonstrators: 34 – Albion Street / The Hithe

The term 'meanwhile use' represents a range of strategies that can be put into place to make under-utilised spaces and places become productive, both in an economic and social sense. Sites set for redevelopment often remain unused for a long time before construction begins, leading to unnecessary expenses for security and hoarding. Some businesses have evolved to offer meanwhile use construction for these underused plots, but finding a willing site can sometimes be difficult. Landowners can achieve increased rental income by identifying opportunities for 'meanwhile use' prior to longer-term redevelopment and actively working with the organisations offering meanwhile use construction. In London, there are 466 suitable plots, totalling nearly 500,000 sqm, showcasing the significant opportunity for meanwhile use, and thus increased rental income for public and private landowners in the UK.

G. Local authorities can help to create circular supply chains by driving demand for novel remanufactured secondary materials by adopting their use in public projects.
Related demonstrators: 12 – Glulam from secondary timber

Local authorities can support circular supply chains by instructing procurement teams to specify secondary materials in public projects. This will help local authorities to meet their carbon reduction objectives, while increasing the market for novel remanufactured secondary materials. The demonstrator project showed that deconstructing timber framing was estimated to add 15% to the demolition contractors' costs, however there is a holistic economic benefit to the area if more construction spend is retained in the local economy. This spend also helps new businesses to expand and reduces their costs, increasing the competitiveness of circular supply chains in the longer term. In the demonstrator, using secondary timber in glulam manufacture can achieve a 40% reduction in embodied carbon compared to conventional production. Understanding and communicating these environmental benefits of using novel secondary materials in projects will be key to resisting the pressure to revert to business as usual. The success of this business model relies on having enough secondary materials for big projects to enable consistent demand.

H. Public asset owners and housing associations should include assessments of whole life carbon, resource consumption and waste generation in strategic decision-making over retention and retrofit versus demolition and redevelopment
Related demonstrators: 17 – 1970s housing estate – Taastrupgard, 14 – Horner Geest

Public asset owners and housing associations should include assessments of whole life carbon, resource consumption and waste generation in strategic decision-making over retention and retrofit versus demolition and redevelopment. Assessments have shown that the transformation of socially challenged developments can be considered a win-win, aligning with both social and climate concerns, particularly when coupled with ambitious climate impact reduction initiatives and sustainable practices like repurposing and reuse. Through such assessments, demonstrator 14 showed that by updating and modernising apartment buildings, we can reduce carbon emissions by 4.5 kg per square meter of living space. Economic analysis shows a 20.9% cost reduction per square meter for demolition and construction/modernisation, building a case for retention and retrofit versus demolition and redevelopment.

I. Local authorities can help to create circular supply chains by driving demand for novel DfD construction by adopting its use in public projects.
Related demonstrators: 25 – Hamburger Klassenhäuser – Slab construction,
26 – Hamburger Klassenhäuser – Façade comparison

Local authorities can play a pivotal role in reducing future embodied carbon emissions and promoting circular construction by leading procurement teams to specify DfD in public projects. While resource savings are a large driver for implementing DfD techniques, the CIRCuIT demonstrators also found financial benefits. Demonstrator 26 found that in comparison to the basecase, the circular construction intervention adopting DfD facades resulted in an overall cost reduction of 61 % over the building's life cycle. Implementing novel construction techniques requires commitment and understanding from development and regeneration officers who must champion the policy through project briefs and challenges. Collaborating with innovative, circular businesses can enhance a local authority's reputation. The scalability of this business case depends on the availability of ready-to-use products and increased market demand driven by progressive purchasing and tighter regulations.

J. Local authorities can achieve faster, cheaper school construction and the ability to adapt sites to rising and falling school-age populations by procuring DfD construction
Related demonstrators: 25 – Hamburger Klassenhäuser – Slab construction, 31 – Vantaa Hybrid school

Local authorities can achieve faster, cheaper school construction and the ability to adapt sites to rising and falling school-age populations by procuring DfD constructions for schools. Demonstrator 31 showed that enabling larger degrees of flexibility in school design would allow the buildings to adapt to changing future needs without requiring major construction works, bringing carbon, material and cost savings. This business case could potentially be replicated to all future school projects in which could potentially result in significant environmental savings and increased efficiency of school space for the city at large.

K. Private asset owners, investors and developers can gain recognition and market differentiation by adopting novel, remanufactured secondary materials
Related demonstrators: 5 – Stablen / The Stack, 10 – Component reuse of retail unit,
12 – Glulam from secondary timber

Embedding circular strategies into construction can allow private asset owners, investors and developers to gain recognition and market differentiation. Effective use of remanufactured materials can highlight the private asset owner, investor, or developer as a sustainable lead in the industry. Strong carbon benefits can be found by embedding this approach as well. Demonstrator 5 showed that by using 58% reused and 42% new glulam beams, there was a 47% reduction in overall carbon impact of the project. This approach was also shown to reduce costs 12% compared to using only new beams. This specific approach could be applied in other types of buildings that have a beam structures.

L. Private asset owners, investors and developers can develop expertise in identifying and transforming underused assets
Related demonstrators: 15 – Gröninger Hof Parkhaus, 24 – Transformation of 31-34 North Row

Private asset owners, investors and developers can develop expertise in identifying and transforming underused assets to reduce construction costs and increase social value. For example, demonstrator 15 highlighted that there is a large market for the transformation of unused car parks, especially in cities like Hamburg that are transitioning away from cars to more sustainable travel. This transformation of underused spaces can contribute to the creation of valuable living and social and commercial spaces in inner cities. The total construction costs were also found to be 5% lower in the transformation model.

M. Private asset owners, investors and developers can relocate entire structural steel frames by connecting to others' project needs

Related demonstrators: 22 – Extending the life of a large 1980s commercial shopping outlet

Certain assets such as steel frame builds are technically simple to take apart and relocate. Private asset owners, investors and developers have the opportunity to capitalise on this by facilitating the relocation and transformation or selling their assets for the purpose of relocation. Demonstrator 22 illustrated that whole life carbon was improved 47% by applying the relocation and transformation approach as opposed to demolishing and building new. This approach was also more cost effective with a 15% saving in the capital construction cost, and reduced the Whole Life costs by 2%. This points to the value in pursuing the sale of a steel frame asset as a relocatable building.

N. Private asset owners, investors and developers can gain recognition and achieve market differentiation by assessing whole life carbon when deciding between retrofit and demolition

Related demonstrators: 13 – Godewind Park, 18 – 1930s commercial plot, 21 – Adaptive reuse of office buildings for housing in Vantaa

Private asset owners, investors, and developers can gain recognition and should consider whole-life carbon assessments when deciding between retaining and retrofitting versus demolishing and building new on new developments. This approach has strong financial benefits, with the CIRCuIT demonstrator projects illustrating that retrofit scenarios can result in total costs up to 37% lower than new builds over a 50-year period. There were also strong carbon benefits with retrofit scenarios illustrating an up to 23% lower whole-life carbon than new builds. This approach can be scaled with increasing software access, consultants can efficiently conduct whole-life carbon assessments of retention or demolition and rebuild scenarios. To integrate assessments into strategic decisions, developers should go beyond the legal requirements and set ambitious policies. Consistently taking on this approach will also allow the companies to benefit from beneficial market differentiation. Specialising in this approach also enhances resilience against policy/tax shifts that incentivise retrofit over demolition. Scaling retrofit solutions requires familiarity with existing buildings and innovative surveying methods for better data as to existing structures.

O. Private investors and developers can rent out affordable workspace by deploying a portfolio of reusable assets on meanwhile use sites

Related demonstrators: 34 – Albion Street / The Hithe, 36 – Green Street Workspace, Newham

Private investors and developers can increase their return on renting affordable workspace by acquiring demountable and reusable buildings and deploying their portfolio on meanwhile use sites. Land and assets earmarked for redevelopment are often underutilised before starting construction. These periods of under-utilisation of assets are often significantly longer than is first anticipated, due to delays in projects coming forward for allocated sites and delays in implementing existing planning permissions, leading to years of outgoings for landowners. Developers should invest in a portfolio of relocatable assets and market them to owners of underused land. The demonstrator The Hithe found that over thirty years and in comparison to a conventional basecase, the circular construction intervention resulted in a 6% increase in construction cost, but an overall reduced operational cost by 5%, reduced maintenance cost by 13%, reduced renewal costs by 60% and reduced the Whole Life costs by 23%.

Municipality as policymaker

P. Local authorities can help to create supply chains for secondary materials by establishing circular economy construction hubs closer to city centres.

Related demonstrators: 1 – Luruper Hauptstraße, 3 – Musterbude, 5 – Stablen / The Stack, 12 – Glulam from secondary timber

Local authorities can help create circular supply chains for secondary materials by allocating sites for circular economy construction hubs and facilitate partnerships to manage them. These hubs enhance material value retention in the local economy, reducing supply chain length, and creating local jobs. Issues such as limited storage space and high transportation costs for materials can impact reuse opportunities. However, as reuse becomes more visible, costs are expected to decrease. Partnering with organisations experienced in site management is crucial. Temporarily using disused brownfield sites for these hubs can revitalise unused spaces and benefit the urban environment. Such initiatives contribute to evolving urban waste management into a circular economy infrastructure, with demonstrator projects illustrating carbon emissions reductions ranging from 2% to 47%. Policy objectives aimed at achieving waste self-sufficiency should support the development of these sites.

Construction industry – deconstruction and secondary materials management

Q. Demolition contractors can maximise revenue from existing materials by assessing cost/benefit of different deconstruction techniques

Related demonstrators: 9 – Tikkurila School Warehouse

In a circular economy, existing materials are valued and there are market systems in place to sell and exchange materials. Demolition contractors are in a great position to leverage this newfound value by establishing a process of valuing existing materials and costing the necessary deconstruction techniques to extract these materials. Demolition contractors usually view buildings up for demolition through the lens of waste, however when materials are seen as resources the contractors detailed knowledge of deconstruction techniques can be applied to create a new income stream. Knowledge of deconstruction techniques are not yet widely known though there have been success stories of demolition companies refashioning themselves into deconstruction companies specialising in value retention. In the demonstrators various techniques for deconstructing bricks - e.g using hand held power tools, using an excavator – were compared for their efficacy and cost. Handheld power tools were more effective in harvesting undamaged bricks but took significantly longer to deconstruct the building and cost more due to increased labour needs – 17% more than other reclaimed bricks and 69% more than virgin bricks. Using the excavator resulted in reclaimed bricks that were 48 % cheaper than other reclaimed bricks and 24% cheaper than virgin bricks. Understanding the most effective way to reclaim materials can keep costs down and secondary materials of interest to consumers. x

R. Demolition contractors can improve cost estimates by comparing PDA predictions to actual materials arising from demolitions

Related demonstrators: 1 – Luruper Hauptstraße, 2 – Offakamp

Seeing demolition materials as resources as opposed to waste can increase the profitability of deconstruction or demolition work. However, as this is a new sector the practice of deconstruction or selective demolition to retain the value of materials still requires a level of data collection and analysis to determine optimal approaches. Demolition contractors looking to shift from waste management to reselling material resources should approach each project as an information collection exercise and compare PDA results to eventual material arisings from demolition. This comparison will help hone the most effective deconstruction techniques. These demonstrators showed that current method to estimate recyclable content are flawed and onsite demolition and reusing of mixed mineral waste results in lower environmental impacts compared to demolition and being processed in a recycling facility.

S. Demolition contractors can maximise higher quality recycling by streamlining mineral wastes

Related demonstrators: 3 – Musterbude

Demolition contractors can maximise high quality recycling by being more effective in the collection and separation of mineral wastes. Clear separation reduces the likelihood of downcycling of aggregates by allowing more control in terms of performance and aesthetics. The Musterbude demonstrator tested seven different concrete mixes with various levels of recycled aggregate. Aggregate with the highest value recycled material was 55% cheaper than virgin aggregate.

T. New and existing businesses can achieve new revenue streams by launching products based on novel recycling and remanufacturing processes

Related demonstrators: 12 – Glulam from secondary timber

There is growing interest across the industry to reduce the carbon impacts of projects by increasing the proportion of material that is reused or recycled. This poses an opportunity for new and existing businesses to achieve new revenue streams by launching products based on novel recycling and remanufacturing processes. For example, the Glulam from secondary timber demonstrator showed that reclaimed timber can easily be worked and transformed, allowing it to serve various functions like structural columns and beams. Challenges include obtaining reliable material sources within a useful timescale, characterisation of the material in terms of material grade, and identifying metallic fasteners in the material as removal is crucial to avoid damaging the tooling used in the formation of the glulam. A significant amount of construction waste is downcycled, so there is significant scope for upscaling this solution.

U. Demolition contractors can achieve new revenue streams by becoming retailers of recovered materials

Related demonstrators: 5 – Stablen / The Stack, 8 – Vantaankoski school, 9 – Tikkurila School Warehouse, 10 – Component reuse of retail unit

Demolition contractors can find new ways to make money by becoming experts in urban mining and reclaiming materials for reuse, remanufacturing, or high-quality recycling. In terms of reselling components demolition contractors traditionally focus on high-value goods for heritage projects, however there is a growing demand for other secondary materials like structural steel. In one demonstrator project, deconstructing a steel frame added £50/tonne to costs, but the resale value is approximately £80/tonne, making it financially viable for demolition contractors to sell. Simplifying deconstruction through improved skills and technology, along with a better understanding of secondary material markets, can reduce costs and enhance feasibility even further. Greater demand for secondary materials, driven by progressive purchasing and carbon regulations, can increase profit margins and expand the range of recoverable materials.

Construction industry – designers and supply chain

V. Designers can become building transformation specialists, capable of rigorously assessing a range of approaches to building retention and adaptation

Related demonstrators: 19 – Korso School, 24 – Transformation of 31-34 North Row

Thriving in the circular economy will require rethinking the entire construction process from design through to demolition. On the design side this means designers must become specialists in transformation – being able to assess a range of approaches to building retention and adaptation. Initially this can support the design organisation differentiating themselves as a leader in the sustainable construction field. As policy requirements for circular approaches and low embodied carbon construction grow, specialising in transformation will futureproof design agencies against future requests and requirements.

W. Manufacturers can generate new revenue streams by developing demountable product-as-a-service business models.

Related demonstrators: 27 – Neustadt – Partition walls, 29 – DfD modular façade – Taastrupgård, 32 – DfD warehouse, 36 – Green Street Workspace, Newham

Manufacturers can make money by leasing building products, like partition systems, and keeping ownership for future savings. In the demonstrator projects, systems designed for disassembly had 11–25% higher upfront costs but saved 13–25% when used a second time. Real savings were seen in the Neustadt example, benefiting manufacturers who can disassemble and re-warrant their products. To make leasing common, there needs to be a mindset shift and considerations for pricing and ownership. While there are financial and organisational risks, keeping ownership of materials protects against future price changes. Leasing works best for shorter-lived components and temporary buildings, raising questions about compatibility among manufacturers. Technology alignment and information retention, like material passports, ensure proper disassembly and reuse, even if the original manufacturer stops trading.

X. Manufacturers can invest in offsite manufacture of slabs and façade elements to enable faster construction

Related demonstrators: 25 – Hamburger Klassenhäuser – Slab construction

Manufacturers can invest in offsite manufacture of slabs and façade elements to enable faster construction and thus make themselves the preferred supplier. Shorter construction times means lower costs for the client, so providing a product that makes this possible while also offering environmental benefits can be a key business strategy. Demonstrator 25 illustrated that byincorporating flexible designs for slabs, a 75% reduction incarbon footprint can be achieved. The economic analysis found that a cost reduction of 37% is possible, when considering two buildings constructed with a 90% reuse potential of the slabs compared to demolition and building new.

Citizens

Y. Citizens can form cooperatives and create new affordable homes and workspace by identifying and transforming underused assets.

Related demonstrators: 15 – Gröninger Hof Parkhaus

Citizens can form cooperatives to collaborate with municipalities to identify and repurpose underused assets around the city transforming them into valuable buildings. In one CIRCuIT demonstrator a citizen cooperative led the transformation of an underused multi-story car park in Hamburg into a mixed use residential development. This approach found a 15% saving in demolition costs and a 5% reduction in total construction costs compared to demolition and new build. Citizen-led cooperatives can enhance feasibility of such projects by building relationships with city planners and investing in alternative residential-led mixed-use developments. Early investigation of existing structures is crucial to understanding and mitigating risks associated with hazardous materials or contamination. Scaling this approach is feasible, particularly in cities aiming to reduce car use, with Hamburg alone expecting nearly 10,000 parking spaces in multi-storey car parks to be suitable for transformation in the next twenty years. Municipalities can support cooperatives by systematically identifying assets at risk of demolition, maximising the potential for their transformation and social, environmental, and economic benefits.

Z. Housing cooperatives and resident associations can assess roof and loft spaces of existing housing for building- or estate-wide densification potential.

Related demonstrators: 16 – 1900s housing urban densification

As cities struggle with housing availability and affordability, expanding existing buildings vertically is a compelling option as it increases density without changing the character of the city area. Assessing this transformation potential for housing cooperatives and resident associations would allow these organisations to create significant additional value for a fraction of the financial and environmental cost of an entirely new development.

CIRCuIT's housing densification demonstrator illustrated that creating new housing via roof conversions is technically uncomplicated but runs into legislative and financial barriers. For this approach to be taken forward successfully, certain apartment requirements such as additional parking spots would need to be lightened or removed. These legislative changes should be possible with close collaboration with the city. A full transformation of the attic space is also too expensive for individual housing owners to consider, even with the rent income from future apartment residents, as construction costs remain high due to the customized nature of building on top of existing structure. Different financial arrangements, such as selling the entire floor to a developer could circumvent this challenge. The environmental benefits of this approach are clear, with the embodied carbon of a rooftop conversion being 48% lower than a comparative new build.

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