CIRCUIT

3

Futureproofing cities: designing for disassembly and adaptability

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821201.

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.

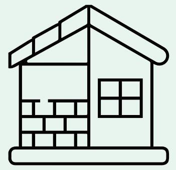
Turning theory into practice

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.

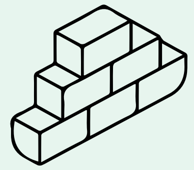
CIRCuIT was a collaborative project funded by the European Commission's Horizon 2020 programme. The project involved 31 partners across the entire built environment supply chain in Copenhagen, Hamburg, Helsinki Region and London.

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

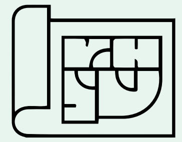
The project's goal was to support the mainstreaming of circular construction practices in the built environment focusing on three key thematic areas:



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.

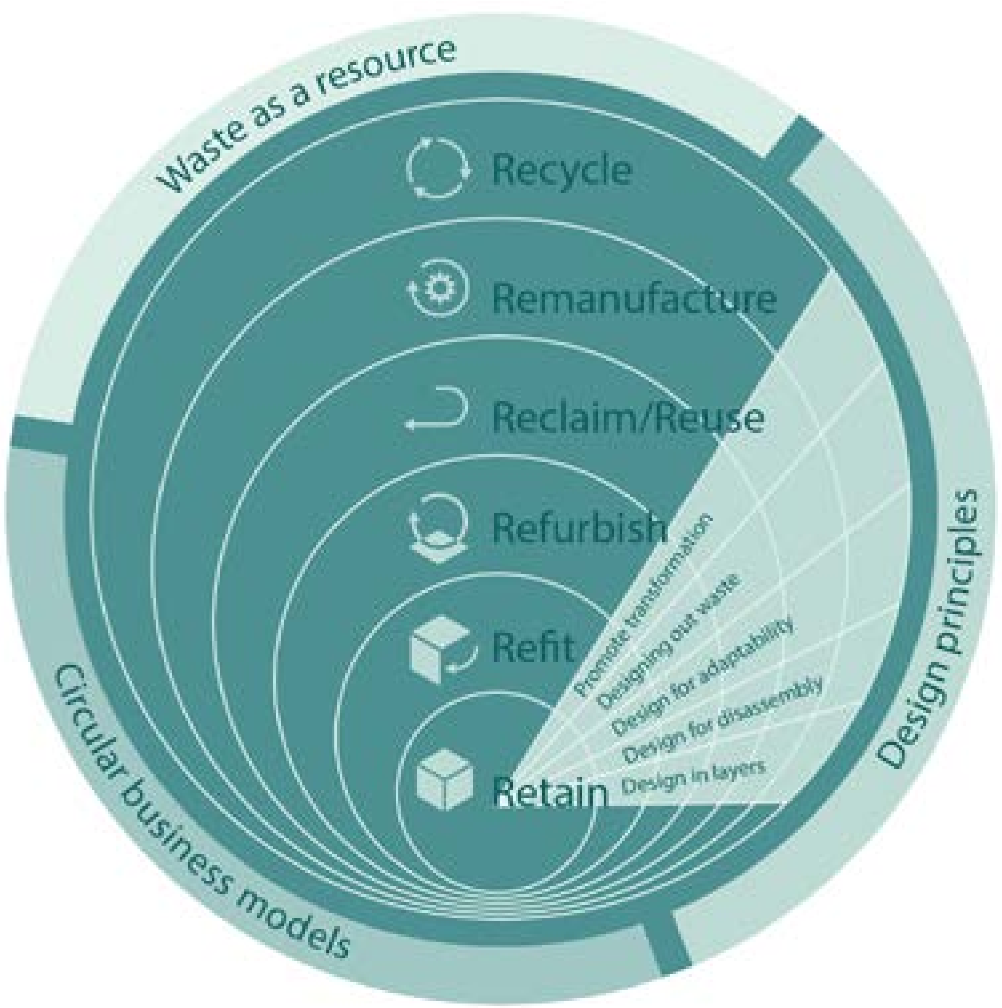
2. It can be done: Real changes are possible by defining a common agenda and applying tools that enable cities to work smarter given the same resources. CIRCuIT has developed tools that can help cities and their stakeholders embed circular economy practices, such as the transformation tool which supports 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.

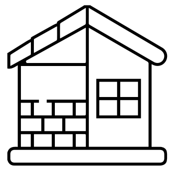
Changing the way that the industry designs, constructs and transforms buildings and infrastructure is critical in the fight against the climate crisis. Thanks to the wide array of tools, case studies and datasets developed by the CIRCuIT project, stakeholders across the value chain are better equipped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



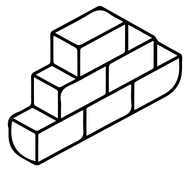
Key findings:

- 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.

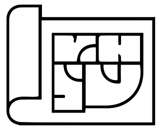


Key findings:

- 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.

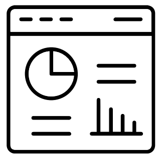


Key findings:

- 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.

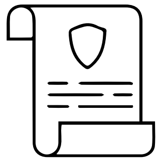


Key findings:

- 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.

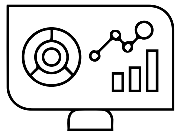


Key findings:

- 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

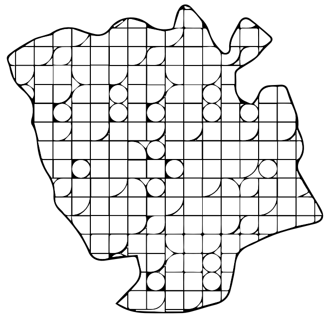
If cities are to increasingly transition to circular construction, it's critical that decision makers and built environment professionals have access to tools that can help them turn circular construction theory into practice. As a result, CIRCuIT's project partners developed five online tools to improve 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

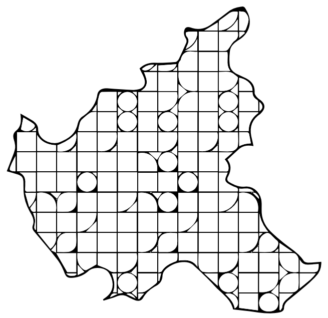


Copenhagen

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.

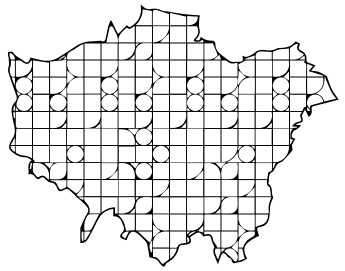
Copenhagen sets ambitious climate goals, aiming to be the world's first carbon neutral capital. It will achieve this through a city-wide transition toward sustainable energy supply, building retrofits, circular waste management, sustainable public infrastructure and mobility, as well as other key initiatives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

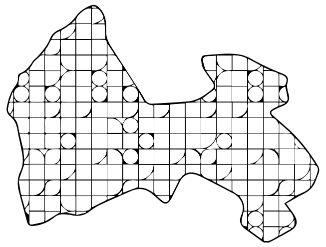
It is currently delivering several EU-funded Interreg and Horizon 2020 projects on urban development, circular economy and smart city elements, harnessing the power of innovation to progress towards its circular goal. In addition, in recent years Hamburg has set up ambitious climate transition targets 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.

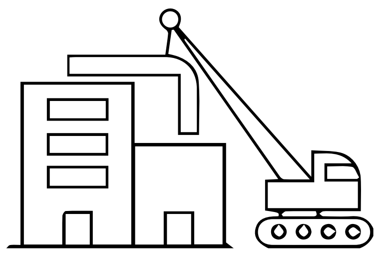
Design for disassembly and adaptability: why it matters

By 2050, another 2.5 billion people are expected to live in urban areas. To accommodate these people and meet their needs, it's estimated that buildings and infrastructure equivalent to a city the size of Milan (1.5 million people) will need to be constructed every week until 2050. As a result, it's critical that the construction of necessary new buildings involves less resources, uses more reused and recycled materials, and reduces the need for demolition and further construction in the future.

Two circular construction approaches that can play a key role in achieving these goals are design for disassembly and design for adaptability:

Design for disassembly (DfD) is an approach to planning and designing a building so it can be easily dismantled. This allows the building to be moved or for components to be directly reused in other projects in the future.

Design for adaptability (DfA) is an approach to planning, designing and constructing a building so it can be easily maintained, modified and used for multiple purposes throughout its lifetime, extending its practical and economic lifecycle.



DfD and DfA can help cities meet their housing and infrastructure needs while ensuring circularity in the future

These two approaches can be broken down further into:

Multifunctionality – being able to adapt a space for different use or needs without any disassembly of components.

Transformability – being able to reconfigure and adapt an internal or external structure through partial disassembly of components to suit different use or needs.

Demountability – being able to fully disassemble a space and its components so that they can be reused or recycled elsewhere.

When a new building is designed and constructed using DfD and DfA, it could solely focus on multifunctionality, transformability or demountability, or it may involve a combination of these practices.

Historically, DfD and DfA approaches have been used for centuries. Yet DfD and DfA are not mainstream in the construction industry today, despite the technical solutions needed to carry them out already existing. This lack of adoption is mainly due to the fact that these solutions come at a slightly higher upfront cost in monetary, carbon and material terms compared to conventional construction.

Looking to the future, it's vital that decision makers and building environment professionals think beyond short-term gains and take action that will help to meet long-term climate goals. As shown in this chapter, DfD and DfA can help cities meet their housing and infrastructure needs while ensuring circularity in the future. These approaches will help cities minimise waste, reduce carbon and save money by keeping materials, components or entire buildings in use for longer.

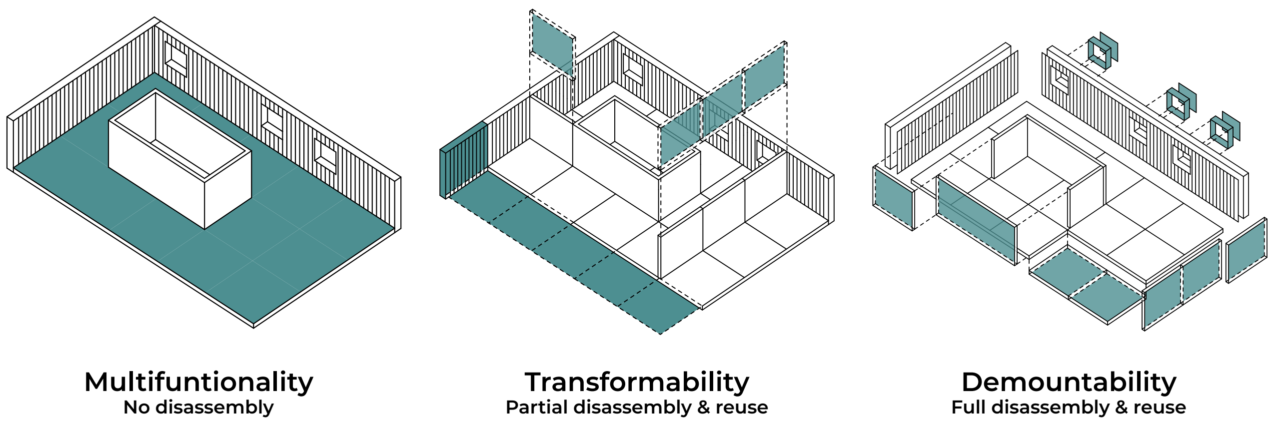


Figure 3.1: Multifunctionality, Transformability, Demountability illustrated

What does design for disassembly and design for adaptability look like in practice?

Working with each other and local built environment stakeholders, partner organisations in the four CIRCuIT cities developed and evaluated 12 demonstrator projects to showcase design for disassembly and adaptability strategies and the benefits they can deliver. 4 are showcased here.

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

Copenhagen

Adaptable housing

Physical Demonstrator

City context

In Copenhagen, new residential buildings tend to be designed to the same specifications. In fact, 66% of apartments have three rooms and the floor area of the flat is between 85–115m2, not including outside areas such as storage space, a balcony, etc.

Currently, prefabricated concrete construction with loadbearing walls are the norm in Danish construction. In this approach, structural concrete elements are cast together to form internal and external walls and floor slabs. However, this limits flexibility, both horizontally and vertically, and the structural elements are difficult to modify without major interventions. Services like underfloor heating, drainage and electricity are often integrated into the concrete. This makes them difficult to access for maintenance or replacement without demolishing part of the structure.

Projections show an increasing need for smaller one and two-room apartments in Copenhagen. But because of the way Danish buildings are currently constructed, it's unlikely a simple layout shift alone could meet future demands. This means buildings are at risk of being prematurely demolished in favour of new dwellings.

DfD and DfA approach

The adaptable housing demonstration project in Copenhagen aimed to show how apartment blocks that use DfD and DfA principles could meet future housing demand and deliver significant environmental and economic benefits.

The demonstrator showcased an alternative structural system based on frame construction. It included a frame system without loadbearing walls. Slabs could be removed to significantly increase adaptability, both horizontally and vertically.

In addition, including mechanical fixings and lime mortar instead of cement allowed components to be dismantled. Design enabling disassembly of building layers, avoiding cast-in services and replacing concrete screed with sand enabled services to be replaced or maintained easily without major interventions.

The demonstrator also included standard prefabricated elements such as concrete columns, concrete core, steel beams and hollow core slabs.

Figure 3.2: 1:1 Model of DfD floor slab

Key findings

Compared to a business as usual (BAU) case study, the DfD and DfA approach had a substantially higher reuse potential (85%).

Results also indicated that the embodied carbon of the BAU approach and the DfD and DfA approach were almost the same after a single building lifecycle. However, if the DfD and DfA buildings were redeveloped, there would be an embodied carbon saving of 37% after the first redevelopment and 50% after the second.

Constructing the alternative buildings and disassembling them would be 25–28% more expensive than using the BAU approach and demolition. However, if the alternative buildings were redeveloped, there would be a 27% cost saving after the first development, and 45% after the second.

Adopting DfD and DfA principles may require a higher upfront investment, but by extending the lifecycle of a building and its elements, there can be substantial environmental and economic benefits after just one redevelopment.

Hamburg

The Klassenhäuser structure – slab construction

Physical Demonstrator

City context

In Hamburg, several schools were built using comparable design concepts. This demonstrator aimed to compare the impact of conventional construction floor slabs against three DfD versions.

DfD and DfA approach

The BAU case for this design was a conventional floor slab made using an in-situ concrete method. Three different types of DfD floor slabs were made using pre-stressed concrete cast elements, pre-stressed concrete cast elements with seam and joint and a bolted timber-concrete construction method to aid disassembly and reuse.

Key Findings

The demonstrator found that the DfD slabs could be dismantled completely and sorted by material type. The DfD floor slabs used 40% less concrete, representing significant material savings and associated carbon impacts. Additionally, the DfD slabs interlocked, which meant, unlike traditional methods, no gaps needed to be sealed.

Using the pre-stressed concrete slab with seam and joint did result in dimensional differences. The DfD school building was 50cm higher than the comparable BAU building, which affected wall heights, staircase and railing lengths, pipe lengths and the distance between the building's columns. These had to be reduced, resulting in more columns and fewer open spaces, which is a drawback that would need to be considered when weighing up the benefits of using this method.

Overall, the demonstrator showed that using DfD slabs could lead to a 70% cost saving over multiple lifecycles of the building, as well as significant carbon savings.

Vantaa/Helsinki region

Design for disassembly warehouse

Virtual Demonstrator

City context

Traditionally, warehouses are designed to remain in a fixed location, be in use for around 20–40 years, then demolished, typically a long time before their technical lifespan is complete. Demolition is more likely to occur because of economic redundancy than technical limitations.

DfD and DfA approach

A single-storey steel framed DfD warehouse was designed that could be dismantled and reused in another location. The warehouse used demountable concrete foundations to allow for disassembly. All connections in the steel and concrete structure were bolted. The columns were also given the option of variable heights, allowing the warehouse hall to be either 5 metres or 3 metres tall. This DfD warehouse was then compared to a conventionally built warehouse in terms of environmental and economic impact.

Key findings

Almost 100% of the DfD warehouse materials could be reused or recycled at the end of life.

Lifecycle assessment (LCA) calculations showed that over three lifecycles (relocating the DfD warehouse compared to building a new conventional warehouse) there were carbon savings of around 40%. Over two lifecycles, calculations showed that the DfD warehouse had significant cost savings, and over three lifecycles the cost saving was 41%.

Overall, it was found that applying DfD methodologies to a warehouse can be challenging because of compliance with regulations for factors such as loads, fire class and building purpose. This challenge should be taken into account in the early stages of DfD design.

London

Albion Street (The Hithe) – Flexible temporary building

Physical Demonstrator

City context

In London, some local authorities have small parcels of centrally located but underused land that currently only host low-value uses such as storage. To trial new uses for the space, 'meanwhile use' construction can be valuable to provide amenities for residents.

DfD and DfA approach

A two-storey affordable office building was designed and constructed using DfD and DfA principles. The building was intended to be disassembled and relocated after 10 years, due to the lease terms for the land it was built on.

The DfD and DfA design was compared against a BAU case study in terms of its environmental and economic impact. A key difference between the two designs was that the DfD and DfA design used modular demountable structural insulated panels (SIP). The BAU design used a traditional steel frame with low-tech timber rainscreen cladding.

Key findings

The economic impact assessment found that the DfD and DfA approach resulted in a 6% increase in construction cost compared to the BAU approach. However, there was a 23% reduction in overall whole life costs.

The results of the LCA study showed an initial 6% increase in whole-life embodied carbon over the BAU base case after the initial construction and use cycle. After the first redevelopment cycle, there was a 30% overall saving in whole-life embodied carbon against the BAU case study. After the second redevelopment cycle, this increased to an overall saving of 46%.

The demonstrator showed that its lifetime could be prolonged by at least 30 years. This was a 200% increase over the BAU case study. It is based on a functional need (use cycle) of 10 years and an ability to accommodate at least two additional use cycles.

The demonstrator targeted a 100% demountable design. However, general wear and tear will likely lead to replacement of materials in a redevelopment. Therefore, a waste allowance of 5% loss during disassembly and 5% loss due to wear and tear was assumed. This means 90% of the building elements for the DfD and DfA approach are estimated to be demountable/reusable.

Embedding design for disassembly and design for adaptability in the heart of cities

Guides and tools to help policymakers embed DfD and DfA approaches in future city strategy, planning policy and city-led projects are lacking. CIRCuIT partners across Copenhagen, Hamburg, Vantaa and London worked with city officials and built environment stakeholders to develop a DfD and DfA Circular Building Roadmap for each of their cities. These roadmaps outlined the best starting point towards DfD and DfA in each city and can serve as inspiration for other cities looking to embed DfD and DfA approaches in their actions.

Following the development of the four roadmaps, CIRCuIT partners identified that roadmaps are usually best integrated into or used for steering existing tools, policies or other roadmaps. If the roadmap remains a standalone resource, it may receive less attention and be less effective.

To make a roadmap a viable tool, it's essential that stakeholders know it exists. Therefore, the roadmap must be promoted to those who can integrate it into existing practices and other tools.

Below, two approaches for a DfD and DfA Circular Building Roadmap are shared. The first is for Copenhagen and features city-driven actions. The second is for London and features design-focused actions.

> **Complete roadmaps for all four CIRCuIT cities are available in the report D6.5 Four city case roadmaps for implementation. Download it at circuit-project.eu/post/latest-circuit-reports-and-publications**

Copenhagen DfD and DfA Circular Building Roadmap: Defining the city's role

City context

Copenhagen is a rapidly growing city. Its municipal plan for 2019 to 2030 proposes the construction of 60,000 new dwellings (around 4.4 million m2). Meanwhile, around 32,000 dwellings are being demolished across Denmark, primarily within the social housing sector.

Most of these dwellings were constructed between 40–50 years ago and their structural materials are still technically sound. The reasoning behind the demolitions is a complex social, political and urban planning issue. However, the fact remains the premature demotion of the dwellings will result in an enormous amount of carbon and materials being wasted.

Using learnings from the CIRCuIT project, there's a great opportunity to influence the approach to the thousands of new dwellings being constructed in the city. The local authority is restricted in the criteria it can set for private developers to increase DfD and DfA. However, it can influence dwellings within the social housing scheme and dwellings built on municipal land.

Of the 60,000 dwellings to be constructed up to 2030, 15,000 (25%) will be social housing. Of these, 8,500 (around 567,000m2) will be delivered by 2030. The steps outlined in the roadmap below put the milestones in place that will increase DfD and DfA within social housing and highlight the city's role in embedding DfD and DfA. The result will have a significant impact on the future circularity of the city.

Actions for implementing Copenhagen's DfD and DfA Circular Building Roadmap

Develop principles and tools for implementing DfD and DfA in social housing

Step 1 – Outline a 'cost pyramid' of use cases that could deliver DfD and DfA in social housing
Use cases outlined a specific situation in which DfD and DfA approaches could add value. These use cases could then be classified in a 'cost pyramid' ranked with cost neutral uses cases at the bottom to more expensive ones at the top. Professionals could then decide which to use, depending on the project.

Step 2 – Develop design criteria and tools for DfD and DfA in social housing
These included guidance on DfA and DfD integration in maintenance plans for social housing and structural, fire and acoustic impact and considerations.

Step 3 – Develop procurement criteria and tools for DfD and DfA in social housing
Circular procurement guidelines have been developed in Denmark. The criteria focuses on a specific percentage target by weight for DfA. Project teams were invited to propose solutions to achieve that target within the budget.

Develop and agree on financial models and incentives for DfD and DfA in social housing

Step 1 – Agree methodology to integrate DfA and DfD in lifecycle costing (LCC)
All social housing in Copenhagen requires a lifecycle cost analysis. But this doesn't cover factors like reuse and adaptability as ways to reduce costs for a building's lifecycle. As a result, a new methodology should be developed covering elements like deconstruction, transportation and adaptation costs.

Step 2 – Investigate integration of LCC in budget allocation and funding for social housing
Budget allocation for social housing is based on a fixed upfront cost, plus a fixed percentage to cover future maintenance and replacement. There's currently no way to increase budget for upfront costs, even if it means savings over the life of the building. Changing this is complex and requires a specialist group to influence funding.

Step 3 – Develop circular financial models for social housing
Based on use cases, there's huge potential to develop new circular financial models for social housing. This could include portfolio-based renovation strategies with material flows between assets. Once tools are in place, financial models should be developed by social housing developers and promoted by Copenhagen Municipality.

Create a city strategy to support DfD and DfA in social housing

It is crucial that the city of Copenhagen communicates its ambitions relating to circularity in housing to inspire change in the industry. A city strategy can help achieve this.

Step 1 – Create and promote a vision for DfD and DfA in social housing
As part of the city vision, it is suggested to include targets for DfD and DfA amongst new construction and for the city to also develop 'future use' scenarios of development areas which might see a change of use in the coming 50-100 years.

Step 2 – Develop pilot projects and showcase to engage industry
Copenhagen Municipality has the potential to support pilot projects through funding, but also by leading the projects in areas where they are the developer alongside social housing associations. Two areas suitable for pilot projects have been identified: By Strømmen and Gammelby.

London DfD and DfA Circular Building Roadmap: Applying DfD and DfA principles to modern methods of construction (MMC)

City context

London has an Affordable Homes Programme (2021–2026) with £4 billion funding to support local authorities and registered providers of social housing to deliver new affordable homes. Projects in London funded through the Affordable Homes Programme must maximise their use of modern methods of construction (MMC). A quarter of all buildings delivered through the programme must use some form of MMC.

The Greater London Authority (GLA) and Be First, the London Borough of Barking and Dagenham's development company, have convened a Buyers' Club to support delivery of high-quality sustainable homes. Its members are largely recipients of funding under the Affordable Homes Programme.

A primary instrument of the Buyer's Club collaboration is a Housing Pattern Book. It provides guidance on designing apartment blocks up to 10 storeys while using design for manufacture and assembly (DfMA) principles.

The main focus of the roadmap for London is to drive demand for MMC and circular construction by influencing the construction approaches and procurement processes of Buyers' Club members. This will primarily be done by suggesting changes in future iterations of the Housing Pattern Book and engaging with supply chains. The steps below emphasise the role that industry can take in promoting and embedding DfD and DfA within cities.

Actions for implementing London's DfD and DfA Circular Building Roadmap

Facilitate greater consideration of full building lifecycle

Step 1 – Set direction of travel
Normalise the consideration of disassembly by adjusting terminology in the Housing Pattern Book and, in due course, in the wider industry. Ensure design teams consider circular economy design principles and approaches by requiring the preparation of circular economy statements across Buyers' Club developments.

Step 2 – Assess the value of circular economy strategies over a building's lifecycle
Given that councils often hold a long-term interest in sites that they develop, make investment decisions based on lifecycle costing (LCC) in preference to capital cost alone.

Step 3 – Digitise information on assets
Being 'digital first' helps make it easier to effectively use and manage building assets through their lifecycle. Tools like material passports (a digital document listing all the materials that are included in a product or construction during its lifecycle) help make DfD and DfA simpler.

Drive appropriate application of circular principles

Step 1 – Design for internal flexibility
Needs of residents and the city's housing mix may change over time. To improve the chances of buildings continuing to meet housing needs, consider the potential for flexibility in apartment sizes and layouts.

Step 2 – Design for adaptability
Changes to demand on building stock are very difficult to predict. However, measures like extra structural capacity, e.g. allowing storeys to be added, will help buildings to adapt.

Step 3 – Design for disassembly
Designing for disassembly helps maximise the reusability of a building's components at the end of its lifecycle. Shorter life building elements should be removable and replaceable.

Step 4 – Set key performance indicators (KPIs) at a building level
Include indicators to measure material use, current material end-of-service-life scenarios, intended future material end-of-service-life scenarios and embodied carbon.

Build the capacity to deliver circular MMC

Step 1 – Create comprehensive guidelines for DfD
Build capacity to deliver circular MMC and increase familiarity with design for adaptability and disassembly among design teams and supply chains.

Step 2 – Engage supply chain with the developed KPIs and DfD guidance
The Housing Pattern Book contains a strong section on circularity and DfD. The guidelines provide technical criteria for design teams to apply through the design process and can frame conversations with suppliers.

Step 3 – Standardise more building elements in the Housing Pattern Book
The Housing Pattern Book already proposes standardisation of bathroom pods and utility cupboards, and it lists additional elements with potential for standardisation: cores, risers, façades and balconies.

Based on RightSizer, one of London's demonstrator projects, floor, ceiling and partitioning systems could also be developed with suppliers to increase internal flexibility, building adaptability and component disassembly. Progressively address standardisation potential of each building element.

Calculating return on investment (ROI) for design for disassembly and design for adaptability

Applying DfD and DfA principles to building design often leads to higher upfront costs compared to a more conventional linear approach. This is typically due to more expensive less often used materials and techniques being used at the outset. However, as shown by CIRCuIT's demonstrator projects (see page 3-5), DfD and DfA often results in economic and environmental savings over the whole life of a building or material.

To increase awareness of this fact and adoption of DfD and DfA approaches, it's critical built environment stakeholders have access to the tools they need to clearly assess and demonstrate ROI when using DfD and DfA. As a result, the CIRCuIT project created a robust methodological framework for assessing the ROI for DfD and DfA across three areas: monetary cost, carbon use and material use.

A second methodology was further developed to assess whether a DfD or DfA concept is likely to be scaled up across a city on the back of its ROI assessment.

> **Both methodologies are covered in more detail in the report D6.4 Part 1 Threefold ROI assessment of building concepts and threefold ROI urban plan – preliminary report. This is available to download at circuit-project.eu/post/latest-circuit-reports-and-publications**

Return on investment methodology for DfD and DfA

In the context of applying ROI to DfD and DfA, the investment refers to the money, carbon or materials going into a project over its lifetime.

For this methodology, the 'net income' is defined as the potential savings achieved in a second iteration of a building compared to a BAU approach. The 'net income' is potential savings compared to BAU of cost, carbon or materials over multiple iterations.

However, the net income can be adjusted to represent any kind of business model that needs to be studied. This can include the resale value of reused materials, the increased rent capture by providing adaptable buildings with higher tenancy, or the simple savings from not having to replace all building elements during refurbishment.

This means the ROI of a DfD or DfA project can be calculated as:

$$\frac{\text{Potential savings over time compared to BAU}}{\text{Upfront investment}}$$

Two types of upfront investment can be identified to calculate the ROI, depending on the business case that needs to be portrayed. This is illustrated in Equations A and B.

In **Equation A**, the upfront investment is the total investment for the DfA or DfD project, which provides a ROI of the project compared to BAU.

$$ROI=\frac{(BAU^{UC1}+BAU^{UC2})-(DfD/DfA^{UC1}+DfD/DfA^{UC2})}{DfD/DfA^{UC1}+DfD/DfA^{UC2}}\times 100$$

In **Equation B**, the ROI is calculated on the additional upfront investment required to deliver a DfD or DfA project compared to BAU, and the potential saving this additional investment can bring. Equation B is only applicable on the cases where the upfront cost of a DfD or DfA project is higher than the BAU.

$$ROI=\frac{(BAU^{UC1}+BAU^{UC2})-(DfD/DfA^{UC1}+DfD/DfA^{UC2})}{DfD/DfA^{UC1}+BAU^{UC1}}\times 100$$

In the equations:

- BAU^{UC1} denotes built as usual upfront investment in the first iteration
- BAU^{UC2} denotes built as usual upfront investment in the second iteration
- DfD/DfA^{UC1} denotes DfD or DfA project upfront investment in the first iteration
- DfD/DfA^{UC2} denotes DfD or DfA project upfront investment in the second iteration

To illustrate the difference between the two calculations, the costs involved in the adaptable housing demonstrator project in Copenhagen are used in the two equations.

EQUATION A:

$$ROI=\frac{(5{,}437+5{,}437)-(6{,}757+1{,}081)}{6{,}757+1{,}081}\times 100=38.83\%$$

EQUATION B:

$$ROI=\frac{(5{,}437+5{,}437)-(6{,}757+1{,}081)}{6{,}757+5{,}347}\times 100=230\%$$

In the calculations:

- BAU^{UC1} built as usual upfront investment in the first iteration = 5,437 DKK (approximately €729)
- BAU^{UC2} built as usual upfront investment in the second iteration = 5,437 DKK (approximately €729)
- DfD/DfA^{UC1} DfD and DfA project upfront investment in the first iteration = 6,757 DKK (approximately €906)
- DfD/DfA^{UC2} DfD/DfA project upfront investment in the second iteration = 1,081 DKK (approximately €145)

The Equation A calculation illustrates the monetary ROI for the adaptable housing concept in Copenhagen is 38.83% over two life cycles, i.e. the potential money saved over two lifecycles compared to BAU.

The Equation B calculation illustrates the ROI on additional investment to deliver the adaptable housing concept instead of BAU is 230%, i.e. the extra 1320 DKK (approximately €729) a developer spends will potentially result in a 230% ROI over two iterations.

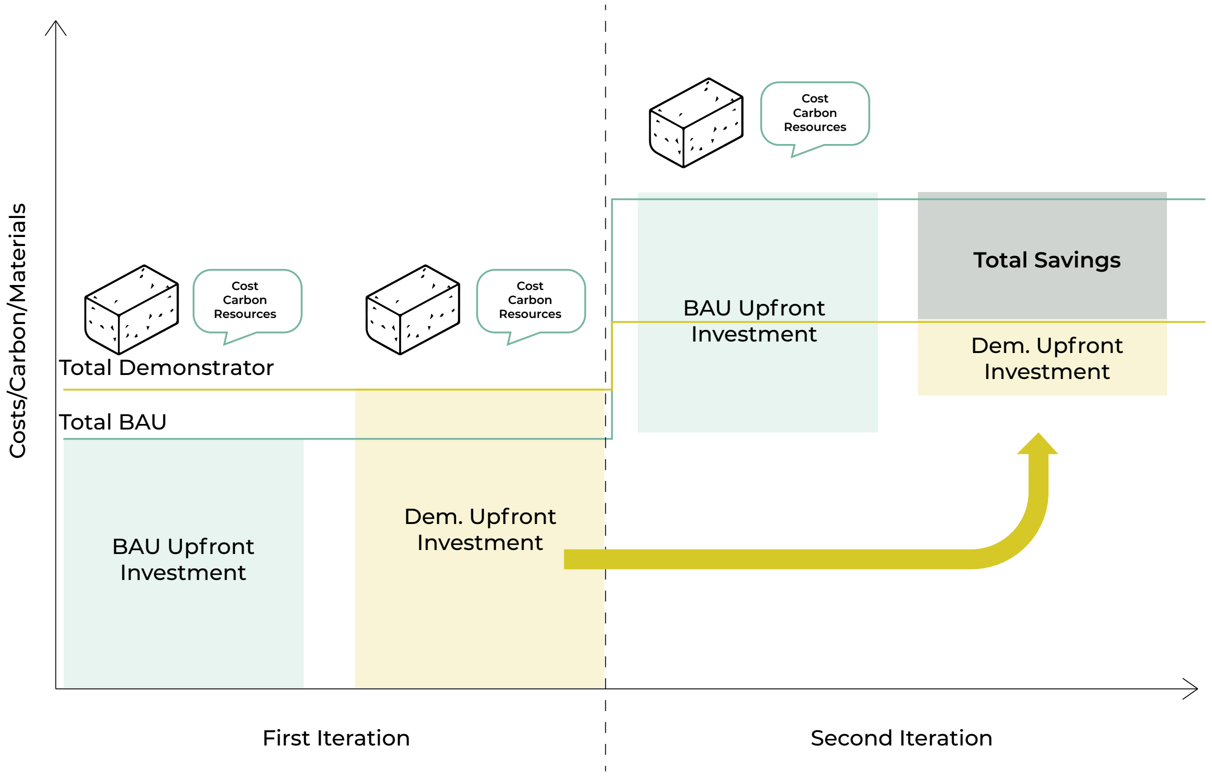


Figure 3.3: Visual illustration of savings after second iteration of Dfd building

Methodology to assess the scaling potential of DfD and DfA concepts

Once a DfD or DfA concept has been established, the scaling methodology can be used to create a 'probability' score. This score determines the likelihood of whether a DfD or DfA concept will be built and then scaled at a city level.

Step 1: Identify an existing source of lost value because of a linear economy in the city
The first step is to analyse current market trends and identify a current loss of value related to a linear construction approach such as premature demolition, vacant land or depreciated building materials. Rate this value loss as significant, less significant or insignificant.

For example, Denmark is prematurely demolishing around 32,000 public housing units. At the same time, 60,000 new dwellings are being built in Copenhagen. Using average data for construction cost and carbon, it's possible to estimate the potential value loss if circular construction practices are not applied to the new dwellings and they are prematurely demolished.

Step 2: Identify a DfD or DfA solution to the value loss identified in step 1
Next, rate how well you think your DfD or DfA solution responds to the identified value loss in step 1. This could be low, medium or high.

For example, adaptable housing (see page 3-6) could prevent Copenhagen from prematurely demolishing buildings in the future.

Step 3: Potential profit score
Use the ROI methodology for DfD and/or DfA (see page 3-18) to estimate the potential profit of adopting a DfD or DfA solution. This could be a cost, carbon or materials profit. Apply this to the scale of the problem the solution will solve to get a full grasp of the potential profit from adopting the DfD and/or DfA concept.

For example, in Copenhagen the monetary ROI for using the adaptable housing concept instead of BAU is 38.83% over two iterations. Applying this percentage to the cost of building 60,000 new dwellings (60,000 x 5,437 DKK) means the city of Copenhagen would save nearly 127 million DKK (170 million Euro) over two lifecycles/iterations.

Step 4: Market readiness score
Analyse the degree to which the DfD or DfA solution is market ready. For example, identify the percentage of market ready components, use of standard dimensions, impact on construction line, etc. Rate the DfD or DfA solution not market ready, somewhat market ready or market ready.

Step 5: Implementation scalability score
Analyse the degree to which relationships between stakeholders and requirements (policy, legislation, etc) are in place to implement the DfD or DfA concept instead of BAU.

For example, if there is a need for legislative changes to building codes, implementation might be very complex. If all that is required is an incentive through planning, it might be less complex. Rate your solution high complexity, medium or low complexity.

Step 6: Conclusion
Based on the preceding five steps, make a conclusion about how probable and scalable your DfD or DfA project is.

Making the case for design for disassembly and design for adaptability

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 a business as usual (BAU) scenario and the outcomes that are expected. Four of the business cases that were developed by drawing on the carbon and cost analysis of the CIRCuIT design for disassembly and adaptability demonstrator projects are shared below.

Each business case includes five perspectives on making the change that are 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 decision makers and local communities.

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

I. Local authorities can help to create circular supply chains by driving demand for novel DfD construction by adopting its use in public projects

Strategic: If local authorities take a leading role in briefing design teams to specify DfD, they can reduce embodied carbon emissions in line with their own carbon reduction objectives and help to break down barriers to the wider adoption of novel circular construction.

Financial: Compared to BAU, upfront costs were found to be 25% lower for Demonstrator 25 and 1% higher for Demonstrator 26. Lifecycle cost savings of 37% Demonstrator 25 and 61% Demonstrator 26 were achieved once the components were used for a second time.

Feasibility: Adopting novel construction techniques 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 the policy is enacted in project briefs and challenged through the course of a project's development.

Appointed design teams will be asked to design and specify product systems in a way that differs somewhat from their normal practice. 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 amongst 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 cases, DfD was found to achieve 75% and 85% reductions in embodied carbon emissions once components were used for a second time.

Scalability: The emergence of building futures contracts and a market mechanism for their exchange will lend credence to the long-term residual value of DfD construction, and justify additional upfront investment.

Nevertheless, the ability to scale this business case depends on the availability of DfD products that are ready to apply to major projects. Greater demand for DfD from across the market, driven by progressive purchasing and tighter regulation of whole life carbon, will create more opportunities for businesses to develop such products.

Related demonstrators: Demonstrator 25 – Hamburger Klassenhäuser – Slab construction, Demonstrator 26 – Hamburger Klassenhäuser – Façade comparison.

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

Strategic: Manufacturers can retain ownership of assets and generate revenue from leasing building products and systems, including partition systems, façade components, warehouse buildings and raised access flooring.

Financial: In the demonstrator projects on which this case is based, upfront costs were found to be higher where systems were designed for future disassembly (by 11–25%). However, lifecycle cost savings were achieved once the components were used for a second time (13–25% saving), and with each additional use cycle this return on investment improved further.

Whilst future returns are inherently uncertain, the Neustadt case showed real savings achieved for the recipient project through the reuse of 200m2 of a partition wall system in collaboration with the original manufacturer. These savings represent a competitive advantage for a manufacturer that is able to disassemble, reassemble and re-warranty their products.

Feasibility: Disassembly and reassembly techniques exist but leasing models remain largely unfamiliar to developers, specifiers and contractors. A shift in mindset is required for these models to become commonplace. Pricing and ownership models need to be considered to suit different component types and market segments.

Risk: There is financial risk in increasing manufacturers' upfront costs with returns coming over a long period. There is organisational risk for existing manufacturers in developing and integrating new business models where traditional upfront sales models are felt to be effective. However, retaining ownership of materials is a hedge against future resource price rises and price volatility.

Scalability: Leasing models are most applicable to shorter lived building components, temporary buildings and typologies that could be expected to be deployed on different sites before the end of the components' lifespans. If they become commonplace, it will raise questions over universality/compatibility versus manufacturer-specific technology (e.g. connection types) and subsequently collaboration versus competition amongst manufacturers.

Alignment over technology (e.g. connection types) and robust information retention (e.g. through material passports) will help to ensure that components are disassembled and reused as intended, even if their original manufacturer ceases trading.

Related demonstrators: Demonstrator 27 – Neustadt – Partition walls, Demonstrator 29 – DfD modular façade – Taastrupgård, Demonstrator 32 – DfD warehouse, Demonstrator 36 – Green Street affordable workspace.

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

Strategic: Public and private developers can create more valuable homes, improve resident satisfaction, reduce lifecycle cost and simplify maintenance and upgrades by developing adaptable housing that facilitates multigenerational living and flexibility of living and working.

Financial: In the demonstrator projects on which this case is based, upfront costs were found to be higher where systems were designed for adaptability (by 21–24%). Savings are achieved when dwellings are transformed to suit changing needs, especially where the alternative is demolition and new construction.

In one case, the redevelopment of an adaptable home compared to demolishing and rebuilding after one use cycle resulted in a 28% lifecycle cost saving. Economic benefits for the building owner may also be generated by shortened periods of vacant flats, due to the capability to adapt flats to meet changing demands.

Feasibility: Adaptability can be achieved through simple design changes such as optimising positions of load-bearing elements and building services layouts and accessibility. The demonstrators apply construction methods and technologies that are readily available.

Risk: The resident survey conducted in Helsinki found that there is demand for flat adaptability amongst both owner-occupiers and tenants, as it reduces the likelihood of having to move house, allows changing use of space as family life and work life change, and makes it possible to rent or sell a part of the flat to yield income.

There is a willingness to pay a premium for adaptability, generally 2–10% on top of the purchase price, if its potential benefits are clearly communicated. For building owners, investment in adaptability reduces the risk of buildings being demolished before the end of their technical lifespan.

Scalability: In owner-occupied housing, the investor and the beneficiaries are different. The potential savings must be communicated and recognised as additional value at the point of sale, otherwise the split incentives will reduce motivation to invest in adaptability. For public developers and housing associations that retain ownership of buildings, adopting lifecycle costing is essential to assess the merit of designing for adaptability.

Related demonstrators: Demonstrator 28 – Copenhagen adaptable housing, Demonstrator 33 – Helsinki adaptable flats, Demonstrator 35 – RightSizer

F. Public and private landowners and asset owners can achieve increased rental income by facilitating 'meanwhile use' of underused land and assets

Strategic: 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.

Landowners can achieve increased rental income by identifying opportunities for 'meanwhile use' and maximising use of land and assets prior to longer term redevelopment.

Financial: Land and assets earmarked for redevelopment are often protected with hoarding and security services in the period before construction starts. These periods of under-utilisation of assets are often significantly longer than is first anticipated, potentially leading to years of outgoings.

Meanwhile use' achieves rental income and avoids the need to pay for securing disused sites, but it requires investment in a temporary building (by the landowner or others) that may need to be deployed multiple times to achieve a return. The demonstrator on which this case is based was a disused brownfield site. Upfront construction costs of a relocatable building to suit a 10-year lease period on the site were found to be 6% higher than an equivalent building not designed to be relocatable. However, lifecycle costs for three 10-year uses of the building were 23% lower.

Feasibility: Information about a site's previous use allows assessment of the capacity of any existing foundations. In the demonstrator case, the 'meanwhile building' was designed to be lighter than the previous building so that no new foundations were required. The demonstrator used standard construction materials and techniques, with some modifications to improve design life and demountability.

Construction supply chains are not fully prepared to scale these techniques to maximise their potential impact, but the supply capacity and skills required are within reach. Deconstruction and relocation expertise exists, but it will also need to be scaled to meet the needs of a larger market in relocatable buildings.

Risk: Maximising return on investment will require 'meanwhile buildings' to be deployed multiple times. Under current regulations, a building will be defined as new at the point that it is relocated to another site. It will require full planning permission and will need to meet the relevant building regulations of the day. This may add complexity and cost to future relocation.

Scalability: All buildings become non-compliant over time, but existing buildings that remain on the same site do not need to be recertified every 10 years. This raises the question – Should relocatable buildings become a new special category and regulations relaxed to simplify their widespread adoption?

Taking London as an example, there are 466 disused plots of land of a size that would be suitable for 'meanwhile use' similar to that adopted by Demonstrator 34. The total area of this land is nearly 500,000m^2. In the UK as a whole, there are 36,000 disused brownfield sites. This represents a significant opportunity to roll out 'meanwhile use' prior to redevelopment.

Related demonstrators: Demonstrator 34 – Albion Street / The Hithe

Further reading

For further information about the outputs featured in this report 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.

- D6.2 Circular building concepts for concrete, hybrid concrete-wood, and volume construction
- D6.3 Set up of demonstrators and scenarios for four partner cities
- D6.4 Part 1 Threefold ROI assessment of building concepts and threefold ROI of urban plan – preliminary report
- D6.5 Four city case roadmaps for implementation

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

Acknowledgements

The following individuals authored the deliverables that form the basis of this chapter.

Ann-Britt Vejlgaar, GXN

Anthony Maubach-Howard, Hamburg University of Technology

Colin Rose, ReLondon

Duncan McNaughton, Grimshaw Architects

Frank Beister, Otto Wulff

Henna Teerihalme, Helsinki Region Environmental Services Authority

Janus zum Brock, Hamburg University of Technology

Jukka Lahdensivu, Ramboll

Jyrki Tarpio, Tampere University

Karolina Bäckman, GXN

Kimmo Nekkula, The City of Vantaa

Lasse Lind, GXN

Maike Hora, e-hoch-3

Marco Abis, Hamburg University of Technology

Masha Doostdar, e-hoch-3

Nichlas Moos Heunicke, GXN

Peter Swallow, Grimshaw Architects

Philipp Wendt, The City of Hamburg

Rachel Singer, ReLondon

Salma Zavari, Vandkunsten Architects

Satu Huuhka, Tampere University

Tessa Devreese, ReLondon

Tiina Haaspuro, Helsinki Region Environmental Services Authority

Uta Mense, The City of Hamburg

Ville Tarvainen, Ramboll

Image credit

Asger Nørregård Rasmussen, Maker

Karolina Backman, GXN

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.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821201.

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