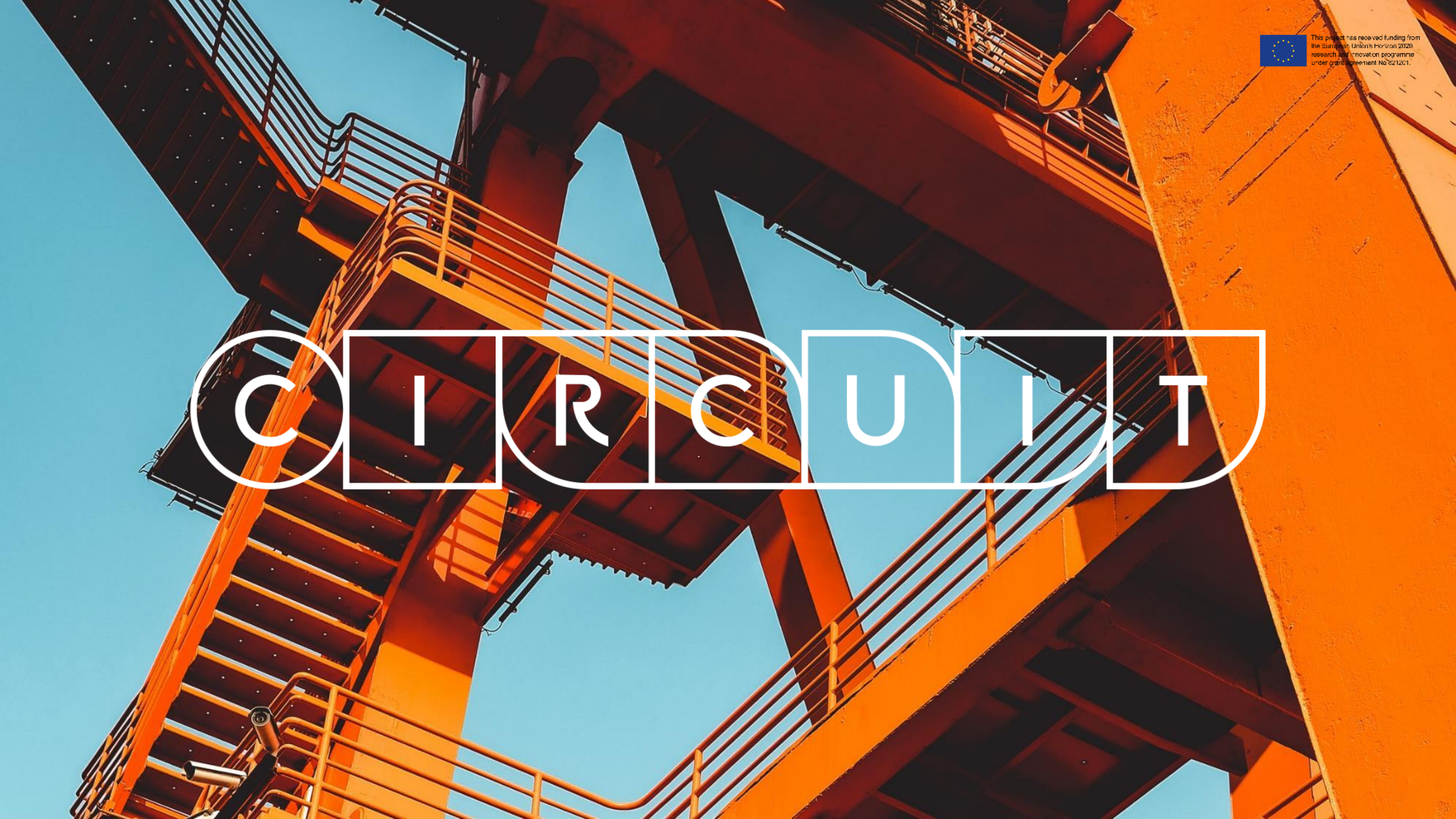

CIRCUIT

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

State of the art on material flow data in the built environment

Summary report

October 2020

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About CIRCuIT

CIRCuIT is a four year collaborative project titled “Circular Construction in Regenerative Cities”, which started in mid 2019 with 30 partners across London, Copenhagen, Hamburg and Helsinki region.

The project focusses on three aspects of circular construction:

- Demolition and reuse
- Refurbishment and transformation
- Principles for designing new circular buildings and future developments

The project also explores city-wide systems such as:

- Governance and planning
- Material and data flows
- Training and knowledge sharing

More details can be found on the project’s website: https://www.circuit-project.eu/

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Our Leading Partners

Our Supporting Partners

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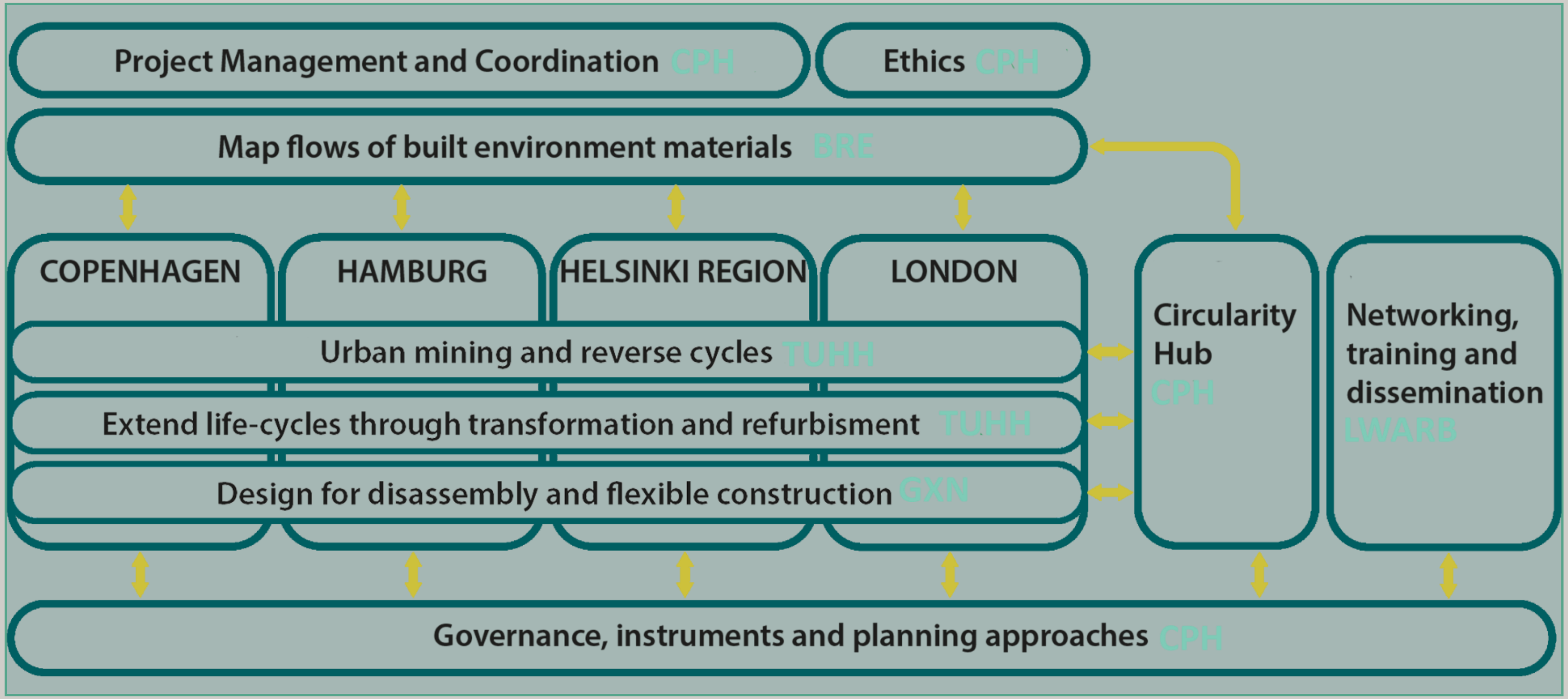
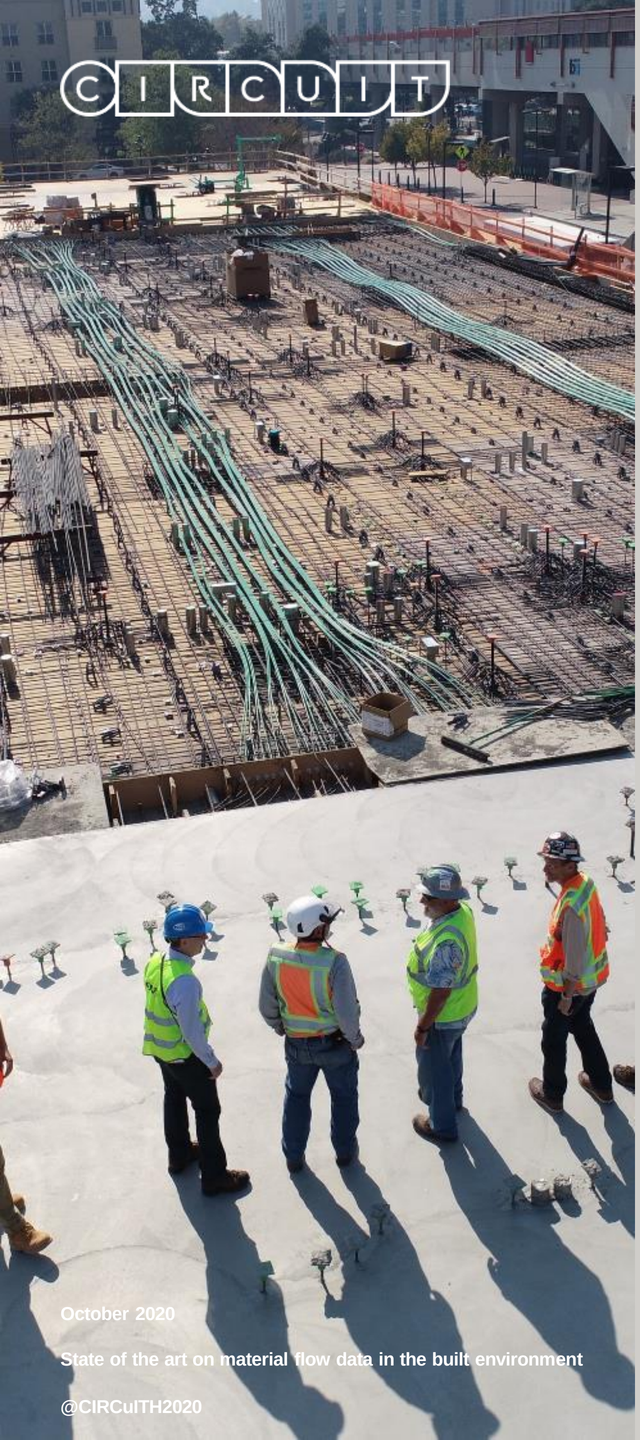
Our work flow





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Introduction

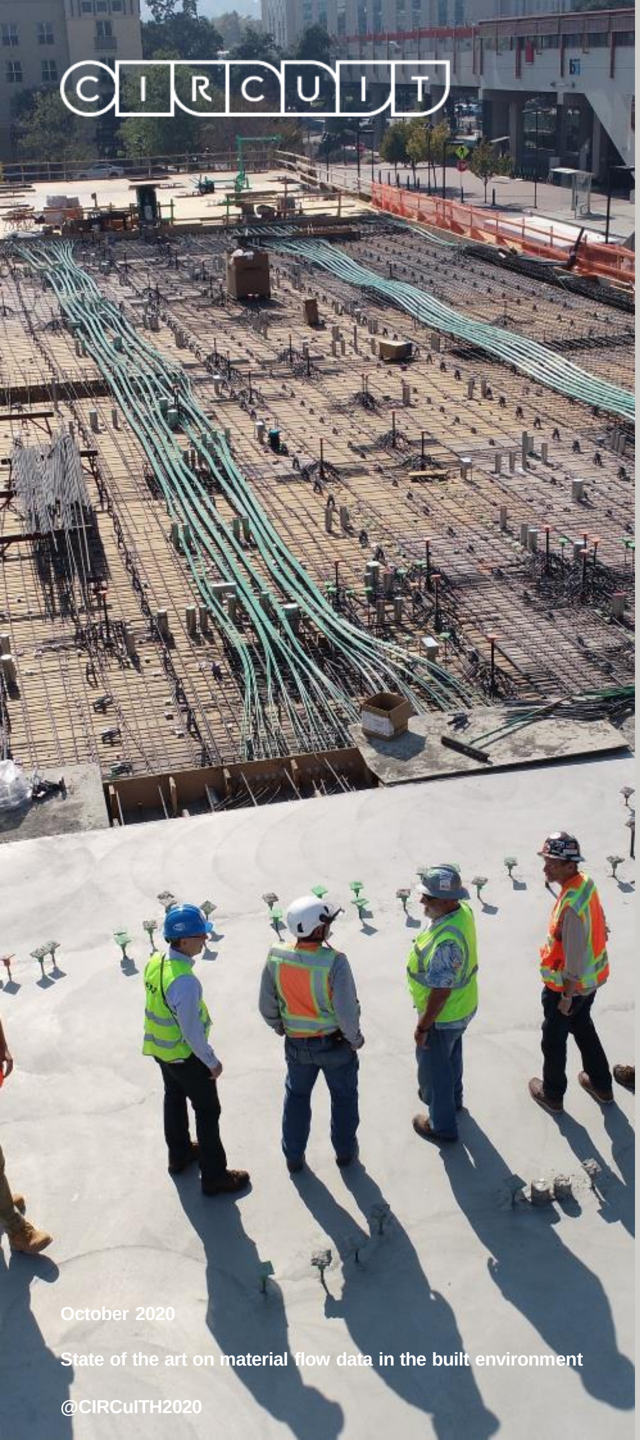
State of the art on material flow data in the built environment

A consistent and comprehensive approach to data collection, analysis and management enables more systematic and evidence-based policy interventions and business models. To support increased circularity in the built environment it is therefore necessary to understand the availability, quality and granularity of existing built environment data.

This report summarizes one of CIRCuIT's tasks that identified and assessed datasets with information on building and infrastructure material stocks and flows in London, Copenhagen, Hamburg and Helsinki region.

The scope, approach and overall assessment of identified datasets are first presented. This is followed by the current status and potential approaches for city-level data in the partner cities along with some dataset highlights. Innovative tools and methodologies for data collection are then discussed followed by overall conclusions.

The technical report was completed in March 2020 and is awaiting approval from the EU. Once published it will be accessible here.



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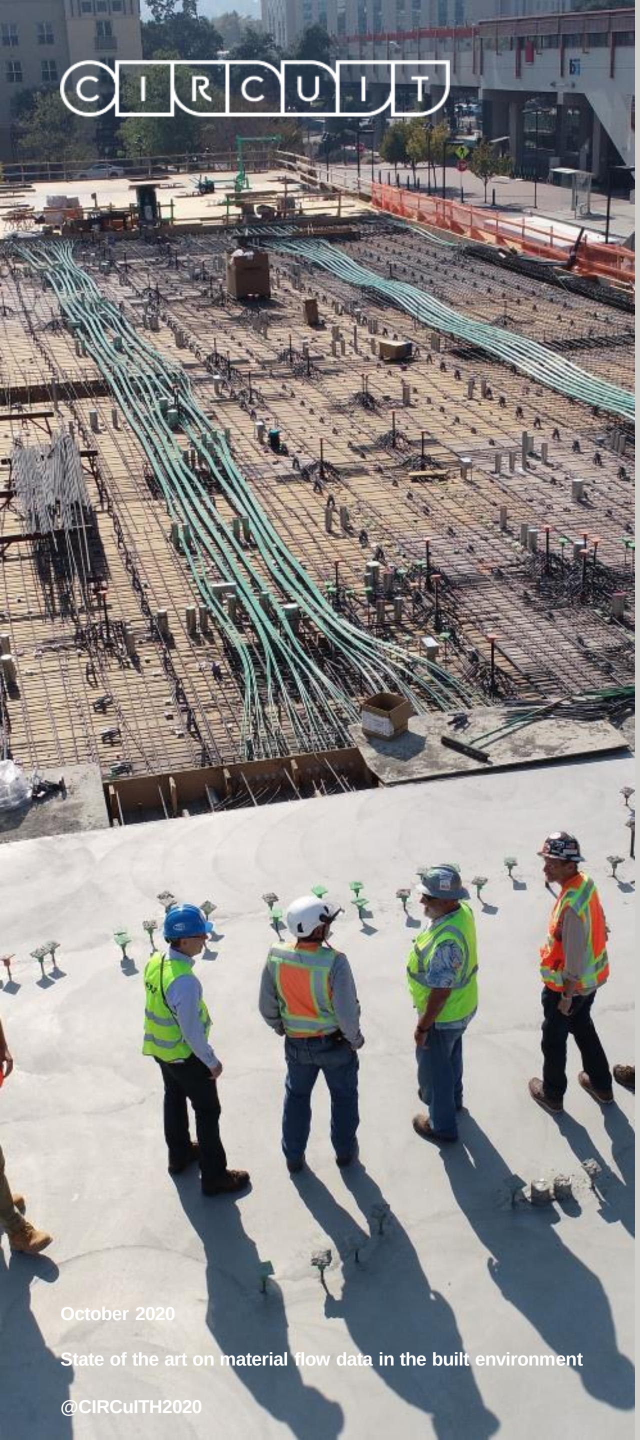
Frequently used terms

Material resources include naturally occurring materials such as stone and timber along with manufactured building and construction products such as components, fittings, and systems.

Material stocks refer to the total materials embodied within existing built structures.

Material flows track materials from their origin to manufacturing to products and components within buildings and infrastructure and finally to their reuse or disposal during renovation or demolition.

Data tables refer to descriptive lists of building and material data sources found across the partner cities.



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Approach

Create data collection template (BRE)

Share template to be populated

BRE London

DTU Copenhagen

HSY Helsinki

FHH Hamburg

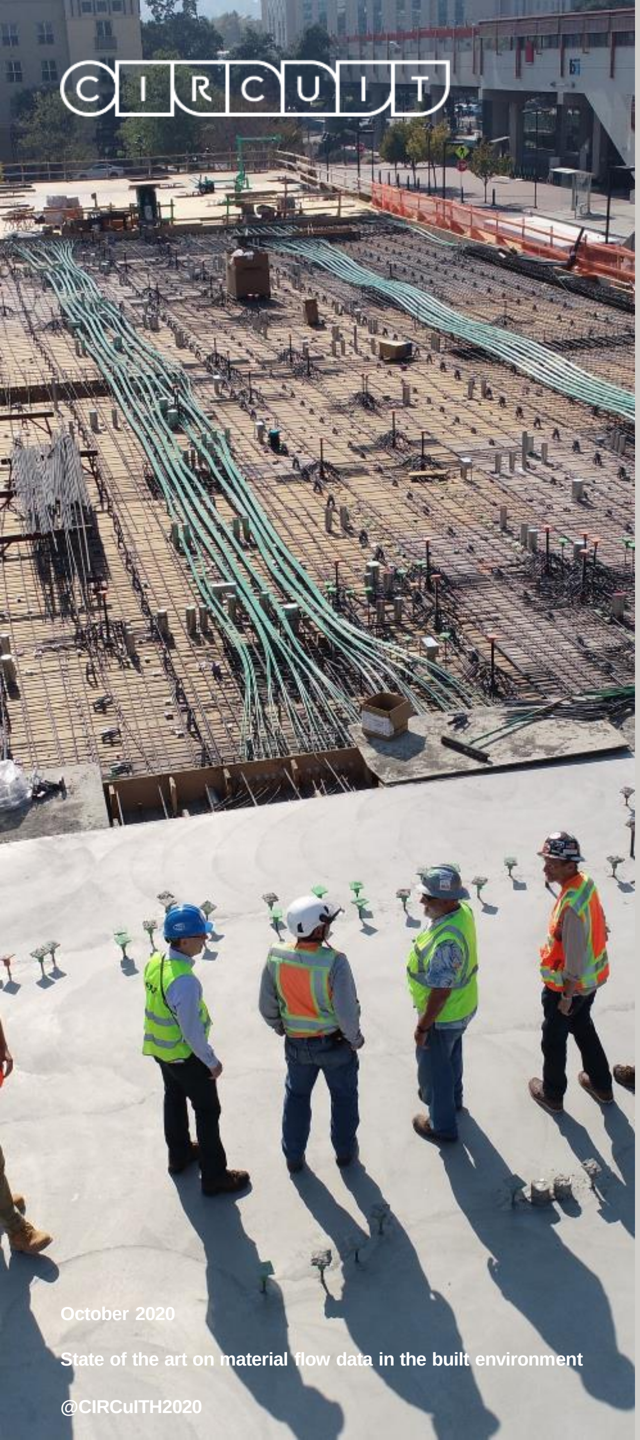
Sources
Academic publications
Industry literature
Government publications
Partner knowledge
Expert stakeholder input

Consolidate and analyse data (BRE)

Feedback
Meetings (individual cities)
Workshop (all cities)
Quality assurance (CPH)

Technical Report & Data Tables
General Presentation

BRE: Building Research Establishment
DTU: Technical University of Denmark
HSY: Helsinki Region Environmental Services Association
FHH: Freie und Hansestadt Hamburg
CPH: Kobenhavns Kommune



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Scope

For buildings and infrastructure, the following types of datasets were searched for in each city:

- Geographical land-use as a basis for mapping and visualisation
- Building and infrastructure stock
- Material stocks at city and building level
- Volume of materials entering and exiting the system
- Material supply and waste chains (raw material extraction, manufacture, supply, installations, renovations, demolitions, waste, reuse, remanufacture)
- Past, current and future material demand (rates of construction, refurbishment, demolition)
- Value optimization within current use cycles, such as adaptive reuse
- Potential to divert waste to circular routes at the end of current use cycles
- Environmental, social and economic impacts
- Relevant policies and trends

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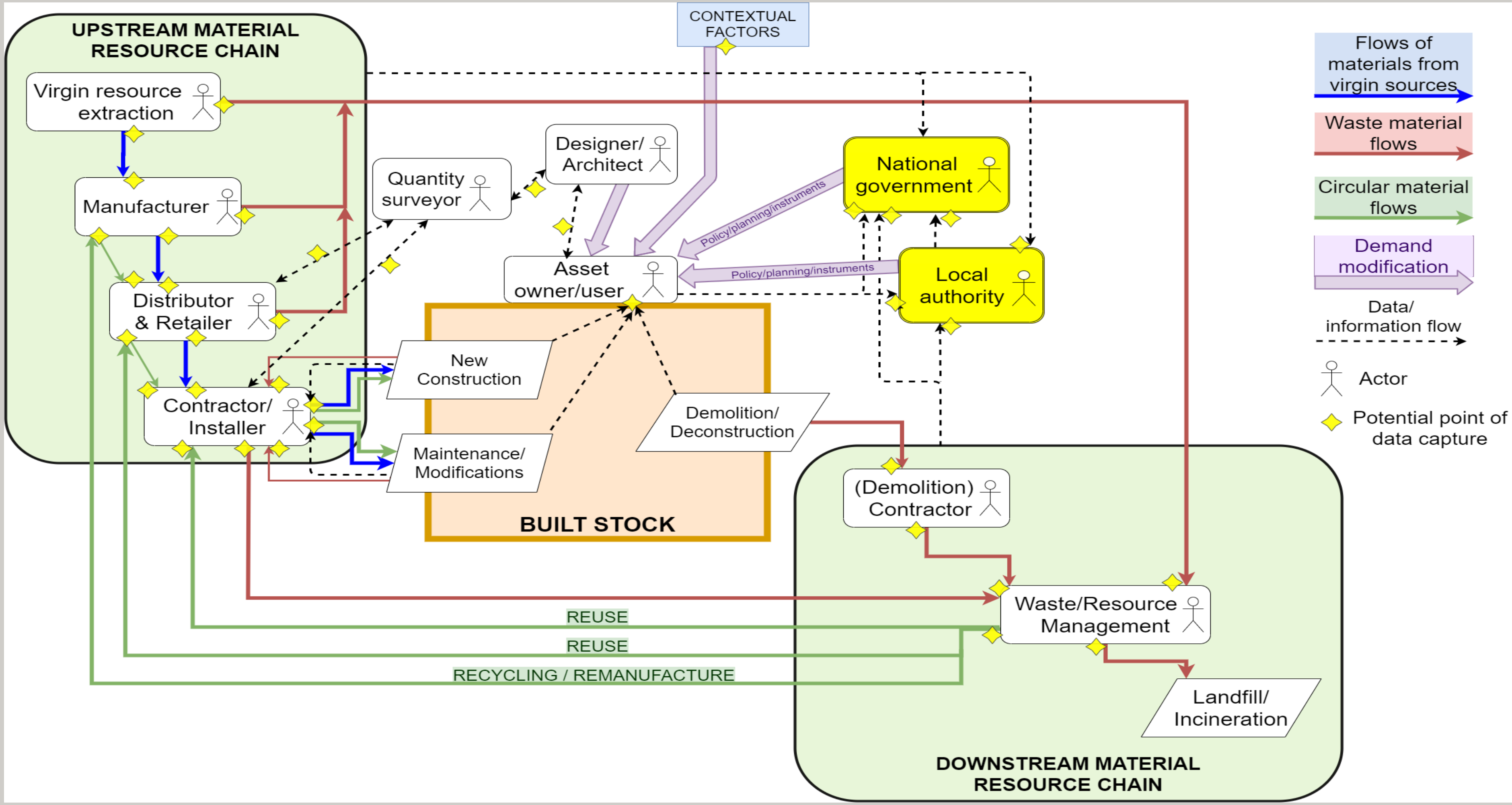
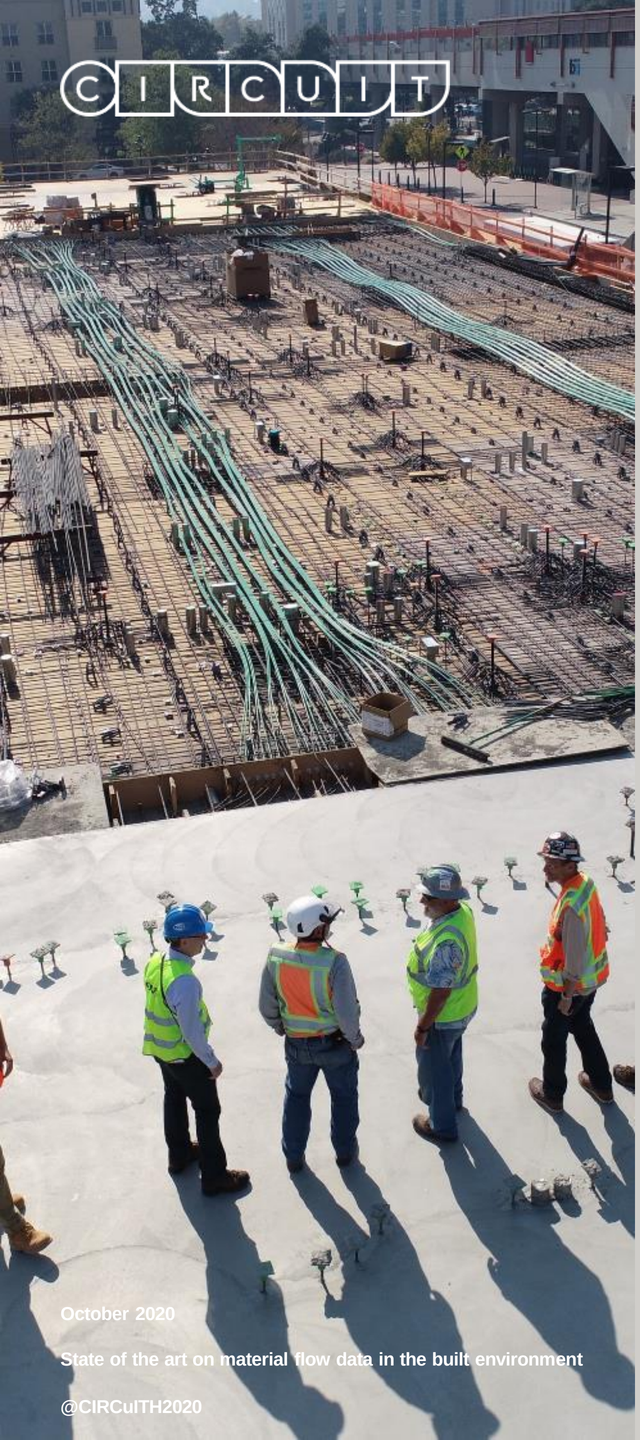
Data capture

Schematic of material flows and potential data capture points



This schematic was produced in collaboration with Alistair Wilson, PhD candidate at Loughborough University.



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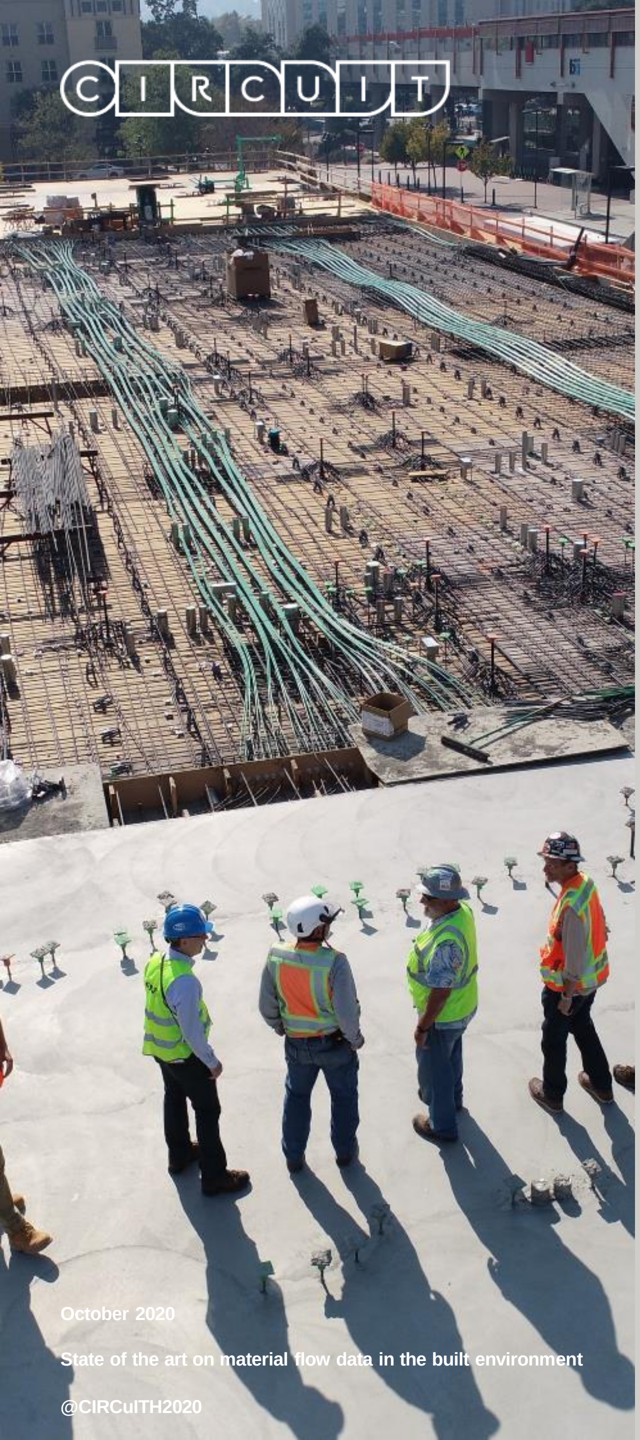
Data accessibility

Open data can be freely used, modified, and shared by any potential user for any purpose. Most of the open data identified across the cities was collated into centralised datasets and shared by local authorities or national government bodies. This data is generally at broad scales with low spatial and temporal granularity, such as building stock figures or waste management statistics at the city or borough level.

There is also a substantial amount of public data that is viewable but should not be freely utilised for the viewer’s own purposes. Obtaining access to this data typically requires authorizations and/or subscription fees.

Organisations involved in the building materials supply and waste chains collect private data that is not openly published. This data is typically collected for a narrow aspect of an organisation’s operations. Private data is unlikely to be widely obtainable within the time frame of CIRCuIT; however, if obtained and aggregated, it could provide a substantially more accurate mapping of material stocks and flows than what is currently covered by open and public data.



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Timeliness, accuracy and reliability

There were significant variations in the age ranges of datasets and how frequently they were updated, if still active. Some relevant datasets are no longer updated. There is typically a delay between data capture and publication, sometimes up to multiple years.

Most data on material volumes or tonnage is based on estimates and assumptions and is open to inaccuracy from human error, double counting and other causes of misreporting. For example, in Copenhagen, data on the Building and Dwelling Register (BBR) is collected by building owners who may lack expertise in surveying and there is minimal systematic verification and assurance. Some datasets rely on extrapolations from old data or on broad and unverified assumptions. Overall, it was difficult to ascertain the accuracy and reliability of data mainly due to poor transparency on methodology.

It was also difficult to ascertain patterns mainly due to the lack of standardization. Discontinuities within material and product classifications, units and formats across similar datasets raises reliability concerns.

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Data availability

Indicative overview of city wide built environment data availability ranked high to low based on accessibility and granularity.

	Copenhagen	Hamburg	Helsinki/Van	London
Land use	Medium	Medium	High	Medium
Infrastructure	Medium	Medium	High	Medium
Building stock: non-residential	High	Medium	High	Low
Building stock: residential	High	High	High	High
Material stocks and flows	Low	Low	Low	Low
New construction & demolitions	Medium	Medium	Medium	Low
Waste management	High	High	High	High
Reuse & recycling	Low	Low	Low	Low
Process and standards	Medium	Medium	Medium	Medium

Key

- High
- Medium
- Low

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Buildings and materials data across the partner cities

Buildings and materials data may be analysed and combined to gain useful insights for CIRCuIT and in general for circularity in the built environment. This section presents an overview of the current status and potential approaches for city-level data in the partner cities. The section closes with one dataset highlight from each city.

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Why are building and material datasets useful?

In a circular economy, products and materials should be managed to extract maximum lifetime value and considered as raw materials for the future at the end of their current use cycle. This reuse of buildings and materials from the existing built environment will reduce the extraction of virgin raw materials, reduce the generation of waste and support the regeneration of cities. Systematic data collection enables the development of effective approaches to circularity in the built environment including three of CIRCuIT's focus areas:

- **Urban mining and reverse cycles** - for obsolete constructions and spaces that are to be demolished, building materials can be reused if an inventory is made and they are properly dismantled.
- **Extend life-cycle through transformation and refurbishment** - for constructions that are no longer suitable for their current use but still have value, e.g. heritage, they can be transformed for other use purposes.
- **Design for disassembly and flexible construction** - for new construction areas where buildings and landscapes are to be developed, buildings can be designed to enhance the future reuse of products and materials, keeping buildings in use for longer.

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Material stock and intensity

Supports urban mining

The detailed quantification of materials embedded in the existing built environment enables more granular material flow analysis and predictions of material outflows upon demolition. Some of the relevant data for these calculations is available at national and city level but not with enough granularity and consistency.

Where there is no available data at city level, bottom-up approaches have extracted data from individual buildings and studies. The diagram describes the availability of various datasets that may be combined to calculate material stocks for each city.

<table>
<tr><th></th><th>Copenhagen</th><th>Helsinki</th><th>Hamburg</th><th>London</th></tr>
<tr><td>Building stock</td><td colspan="4">Open data on the number of residential buildings by various categories (i.e. age, type, location). Less granular data for non-residential.</td></tr>
<tr><td>Spatial information</td><td colspan="4">Open data on building height, floor area or volume for various building types (in some cases 3D buildings data/LiDAR data)</td></tr>
<tr><td>Material intensity</td><td colspan="2">Individual studies for specific materials or building types</td><td colspan="2">Country specific material intensity databases or reports</td></tr>
<tr><td>Materials, dimensions, construction types</td><td colspan="2">Open data for national building stock (but not all materials)</td><td colspan="2">Individual studies for specific materials or building types</td></tr>
</table>

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Building demolition rates

Supports urban mining and extending life cycles

The analysis of historical demolition and refurbishment rates can be combined with other indicators to help predict when secondary materials may become available. The diagram below describes the availability of various datasets that may be used for this analysis. Where there is limited useful data on historical demolitions and future building modification predictions, a less granular approach is to analyse the quantities of waste arising from demolition activities of different building types over time. However, there are limitations with aggregating data by building type since some buildings may deviate significantly from standard assumptions. To quantify variations, data could be collected at borough and/or neighbourhood level on modifications over time for each building type.

	Copenhagen	Helsinki	Hamburg	London
Historical demolitions	Open data from national demolition registers		Sub-city local authority planning submissions (see below)	
Building refurbishments	Demolition and refurbishment data openly available from sub-city local authority planning submissions in searchable databases; however, granular data such as building types and material quantities is either absent or requires analysing notes within individual records.			

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Secondary/reclaimed materials

Supports urban mining

There were no city wide datasets found on how materials are reused at the end of service life or if they are reusable to begin with. Some academic studies investigated typical end of life pathways in each city.

A useful method to identify secondary materials that may become available is a pre-demolition audit, which is not yet a mandatory requirement in each city. Prior to the refurbishment or demolition of a building, a pre-demolition audit report provides data on key demolition products suitable for reuse and recycling. Along with analysing building data such as floor plans, the audit typically includes a building survey to gather data on the volume, weight, type and condition of its structural components and internal fixtures and fittings.

Concrete

Product description

Concrete is the major Key Demolition Product (almost 70% by weight) originating from the concrete frames, floors and stairs. The information provided gave limited details of the construction and some parts of the buildings were inaccessible so these figures are based on estimates from plans and visual assessment.

Location	Volume (m^3)	Weight (Tonnes)
Floor	9954.0	23889.5
Roof	1228.0	2947.2
Staircase	159.2	382.1
External wall	967.4	2321.7
Columns	526.0	1262.4
Walkway	10.3	24.7
Internal walls	89.1	213.8
Total	12934.0	31041.5

Table 3: Sources of concrete

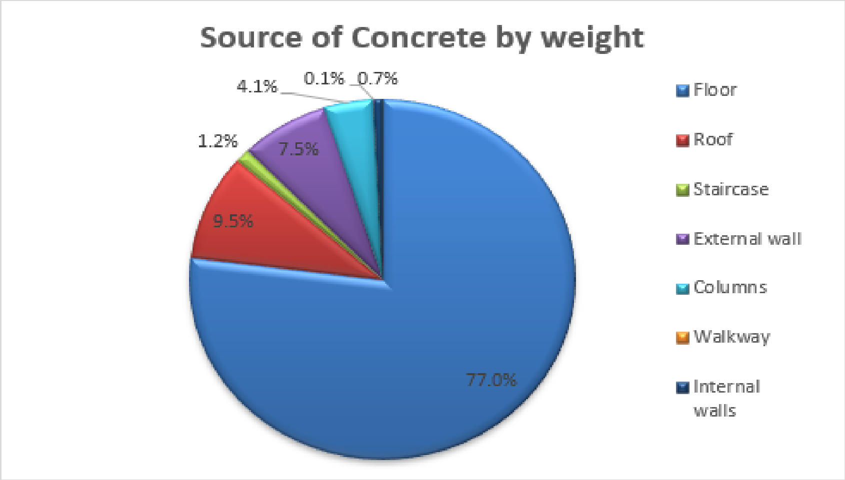

Figure 2: Sources of concrete

Example audit breakdown for concrete. For more information: https://www.europeandemolition.org/industry/ projects/pre-demolition-audit

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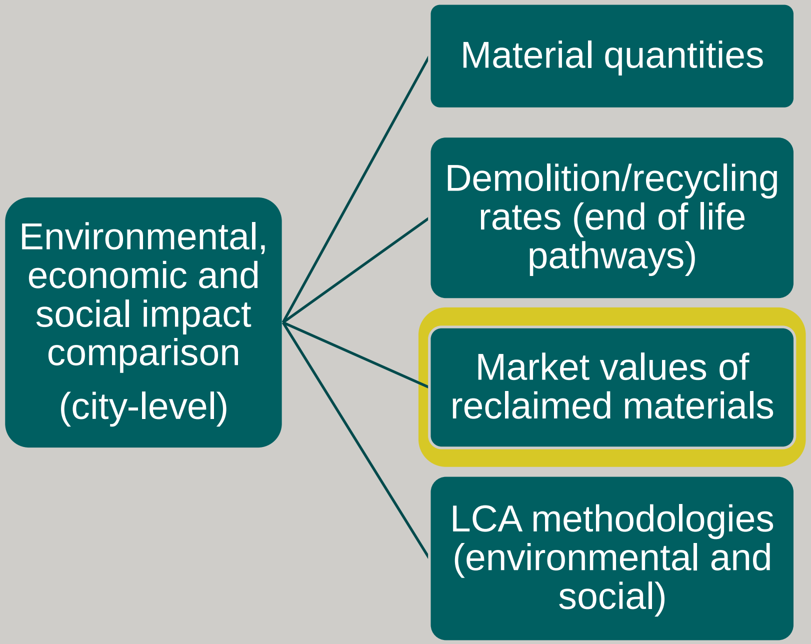
Environmental, economic and social impact

Supports urban mining and extending life cycles

A range of datasets and methodologies, such as lifecycle assessment (LCA), can be combined to model and compare environmental, economic and social impacts of different end of life scenarios. This includes comparing refurbishment or transformation to demolition. However, there is limited to no data on the market values of reclaimed materials which limits economic comparison.

Waste exchanges such as Salvo[1] and waste brokers such as Reconomy[2] may provide estimates of market prices. The Survey of Architectural Values in the Environment (SAVE)[3] methodology, already used in Denmark, may be adapted for the other cities to evaluate architectural heritage.



[1]https://www.salvoweb.com
[2]https://www.reconomy.com
[3]https://www.slks.dk/fileadmin/publikationer/Kulturarv/InterSave_english.pdf

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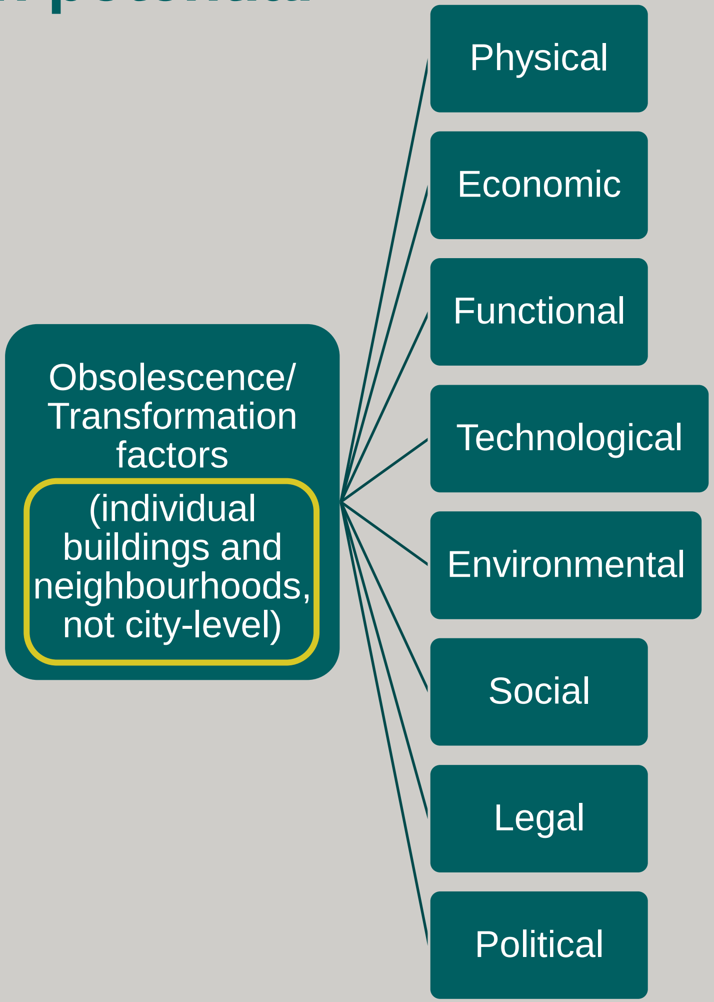
Obsolescence and transformation potential

Supports extending life cycles

Adaptive reuse and refurbishment of existing buildings can facilitate the sustainable transformation of the building stock but obsolete and transformable buildings and neighbourhoods first need to be identified. Currently this requires extensive data collection and analysis on individual buildings and their local context.

Trends within identified datasets on demolitions, abandonment/vacancies and geospatial information may be extrapolated to the existing stock to estimate building types and quantities that are likely to be demolished. However, this process still requires analysis of localized factors[1] such as those shown in the diagram.



[1]Diamantidis, Sykora & Bertacca (2018) Obsolescence Rate: Framework, Analysis and Influence on Risk Acceptance Criteria, Proceedings of the 6th International Symposium on Life-Cycle Civil Engineering

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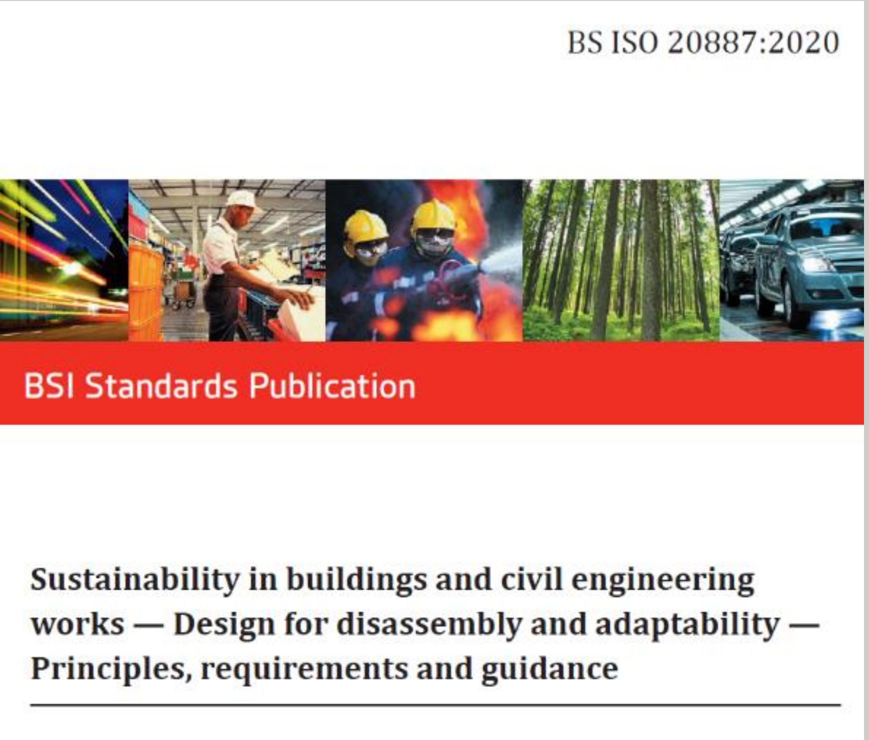
Design for disassembly and adaptability (DfD/A)



Source: https://www.iso.org/standard/69370.html

Supports design for disassembly (DfD) and flexible construction

Showcasing practical methods of DfD and flexible construction could enable sustainable transformation decision-making in industry and government. ISO 20887, published in 2020, provides an overview of DfD and adaptability (DfD/A) principles and potential strategies for integrating these principles into the design process as well as guidance on measuring performance of DfD/A. It would also be useful to have data on the extent to which DfD and flexible construction are currently represented in building stocks; however, no city-level data was identified.

Emerging datasets/methodologies that may contribute to DfD/A data:

- Circular Building Assessment methodologies
- Projections of future material release from different types of buildings may be useful for determining the types of demonstrations most relevant and impactful
- Comparative city-, borough- or neighbourhood-level LCA may highlight how DfD/A may result in different environmental, economic and social impacts.

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Standards and processes

Supports governance and urban planning

Each partner city has various standards and processes in regards to the sustainability of construction but there is a lack of granular and accurate data that can be used towards the creation of circularity benchmarks, targets and interventions. Improved data collection and aggregation is needed. This may require requesting and anonymising private datasets from industry supply chains since some of the useful data is privately held.

Binding plans appear to be drafted at city level, enabling a top-down approach such as Carbon Neutral Helsinki 2035[1] which requires calculating the entire carbon footprint of construction and promoting wooden construction. New projects in London will need to provide Circular Economy Statements that essentially require pre-demolition audits, bills of materials, predicted volumes of waste, etc. If this data can be systematically collected in openly accessible databases, these governance and planning steps contribute to the much needed data integration from construction planning to waste management.

One output example would be the London Development Database (LDD) that is being transformed into a 'live hub' of publicly accessible data and information on individual planning permission requests, approvals and completions as they are received or issued.

[1]https://www.hel.fi/static/liitteet/kaupunkiymparisto/julkaisut/julkaisut/HNH-2035/Carbon_neutral_Helsinki_Action_Plan_1503019_EN.pdf

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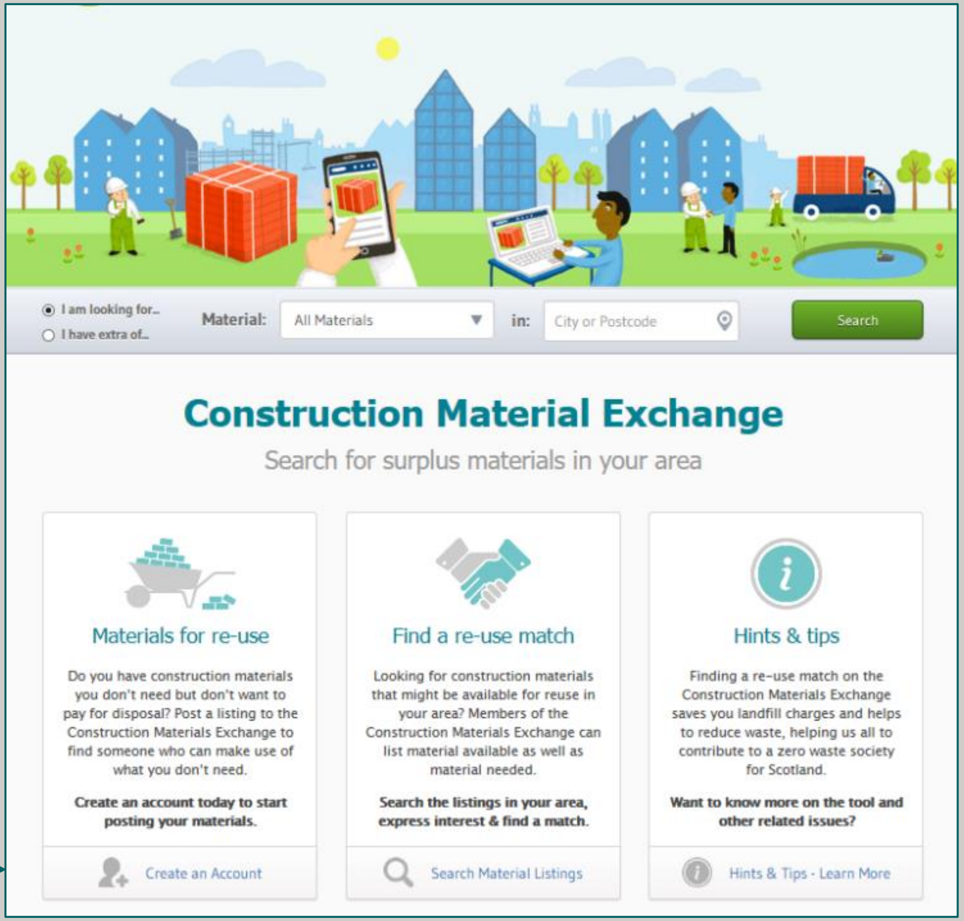
Waste and material exchanges

Supports CIRCuIT's Circularity Hub

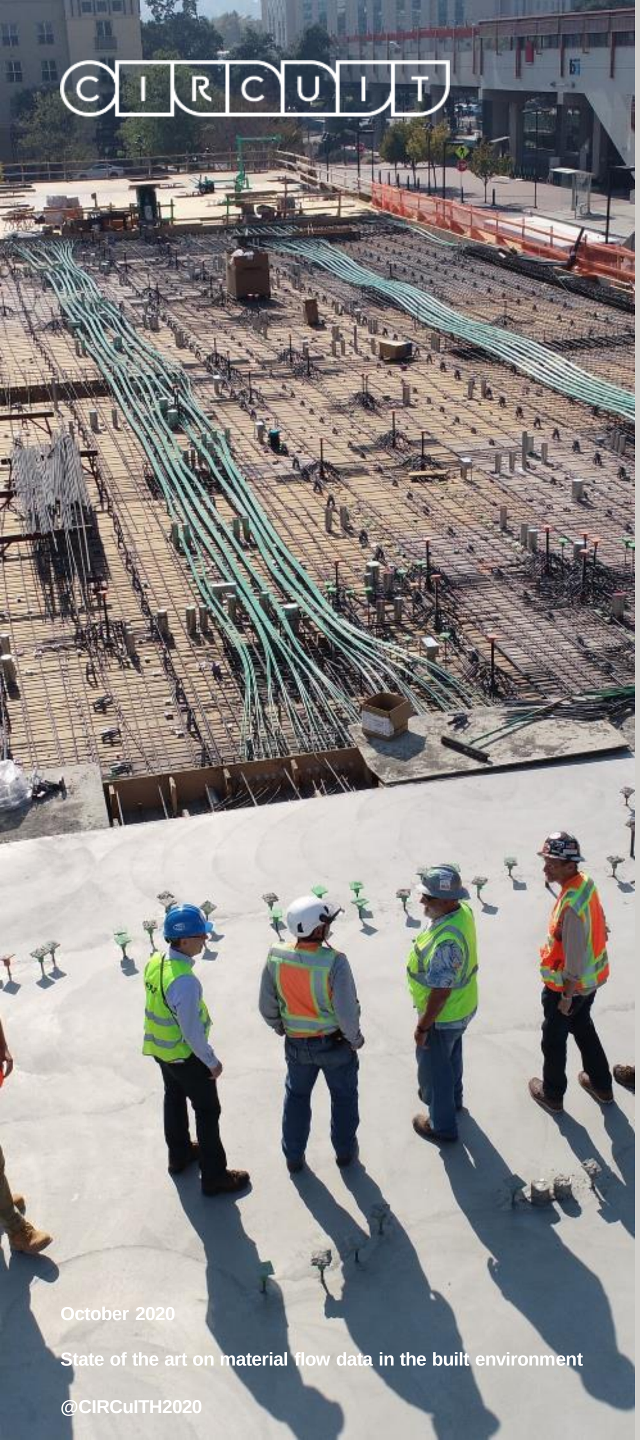
The Circularity Hub being developed during CIRCuIT will be an open access data platform to support circular economy principles in the built environment. One outcome is a Materials Exchange Portal (MEP) that may be an online marketplace for materials released from building and infrastructure stocks.

Similarly, waste exchange websites enable individuals and organisations to give away or sell their waste materials. Within the partner cities, Enviromate[1] and Construction Material Exchange[2] were developed in the UK.

Another outcome of the hub is the Circularity Atlas which will be an interactive GIS tool for policymakers, industry and the public to visualise material stocks and flows in the built environment. This will require remotely-sensed data and land-use classifications that may be obtained from the Copernicus Land Monitoring Service[1]. Previously mentioned datasets may also be integrated. A more complete list of exchange websites and potential datasets for integration can be found in the technical report.



[1]https://www.enviromate.co.uk/aboutus#contact
[2]http://cme.resourceefficientscotland.com/



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Dataset spotlight: Copenhagen

Central Register of Buildings and Dwellings (BBR)

The Danish Buildings and Dwellings Register (BBR) contains residential and non-residential building information for the use of property assessment, population and housing censuses, and statistical purposes. It originated in 1976 and covers all developed properties in Denmark. It is managed by the Ministry of Housing, Urban and Rural Affairs and municipalities submit regular reports.

There are three data levels (https://teknik.bbr.dk/nyttige-links):
1. Property
2. Building
3. Unit

Registered information includes: an identification number, location, purpose, size, year of construction, access conditions, technical conditions, some materials, layout, electric installations and other building updates.

All levels of data on a single property can be openly accessed but will only be in PDF. Raw BBR data on all levels can be openly accessed through the new public data system - https://datafordeler.dk/ - in JSON and XML formats that can be used by GIS programs.

View the technical report for more information on datasets found for Copenhagen.

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Dataset spotlight: Hamburg

Authoritative Real Estate Cadastre Information System (ALKIS®)

ALKIS is a nationally standardized register comprised of spatially referenced (map) and non-spatially referenced (book) data. It is an amalgamation of previously collected real estate (land parcels and buildings) data from different systems. It was created to provide geographic reference uniformity in the German real estate register based on international standards and best practice, such as ISO.

ALKIS is managed by AdV, the official coordinating body for German surveying, in alignment with German federal laws for national official surveying. Overall, the object-oriented dataset contains detailed administrative and geospatial data on infrastructure, land plots and buildings.

The basic standardized dataset is available by contacting ALKIS.
http://www.adv-online.de/Products/Real-Estate-Cadastre/ALKIS/

View the technical report for more information on datasets found for Hamburg.

Example of cadastral map
Source: http://cadastraltemplate.org/germany.php

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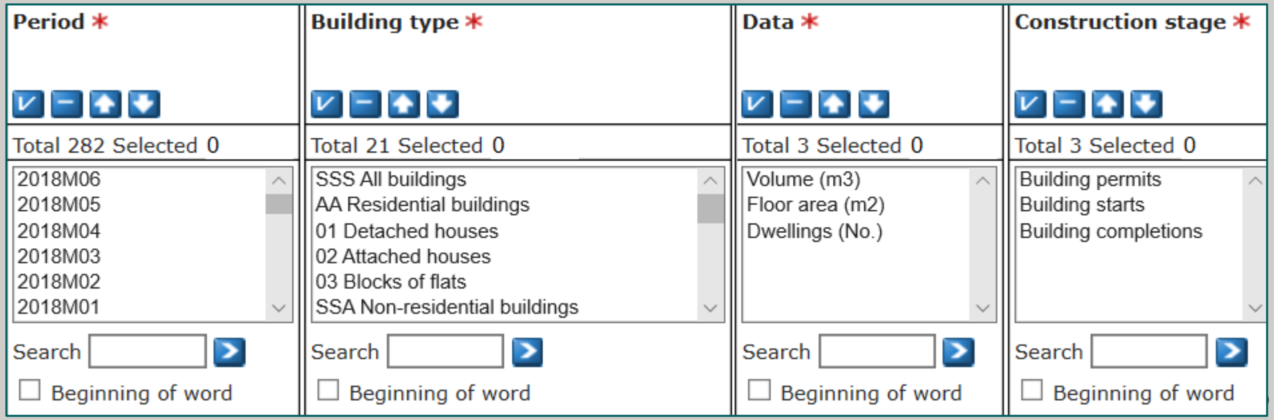
Dataset spotlight: Helsinki Region

Statistics Finland (StatFin)

StatFin openly offers a wide range of easily searchable basic databases down to municipality level. Categories include housing, living conditions, prices and costs, construction, manufacturing and many more.

There is a subscription charge for access to more granular data or it can viewed at the Library of Statistics. Paid datasets include the built environment service that monitors building production and investment and calculates the volume of permitted construction and production. http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/

View the technical report for more information on datasets found for Helsinki region



StatFin construction sub-categories (above)
Building and dwelling production variables (below)
Source: https://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/

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Dataset spotlight: London

Planning Policy Circular Economy Statements

The Mayor of London’s draft London Plan Policy SI7 ‘Reducing waste and supporting the circular economy’ is not an active dataset but encourages project-level data collection that should significantly improve city-level data granularity and support evidence-based decision making. The draft was in development since 2018 in collaboration with built environment stakeholders.

New applications in London will need Circular Economy Statements that demonstrate:

1. Reuse/recycling plans for all materials arising from demolition and remediation works
2. Design for disassembly and adaptability considerations
3. Opportunities for managing as much waste as possible on site
4. Adequate and accessible storage space to support recycling and reuse
5. Predicted waste generation during project and how the waste will be handled.

https://www.london.gov.uk/what-we-do/planning/implementing-london-plan/planning-guidance/circular-economy-statement-guidance-pre-consultation-draft

View the technical report for more information on datasets found for London.

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

Innovative approaches: tools and methodologies

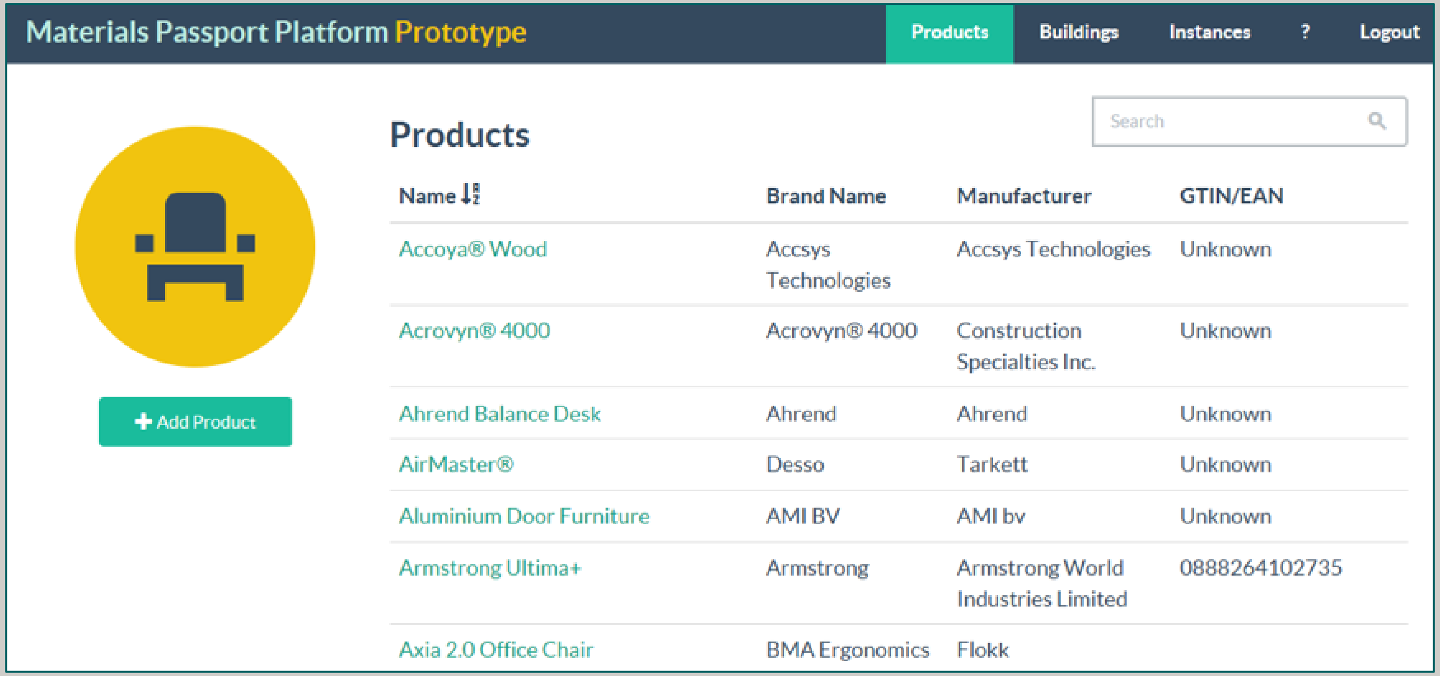
This section highlights some innovative built environment tools and methodologies that may be useful within CIRCuIT and also in general for built environment data collection.

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

Material passports

A material passport is a digitally represented set of data that defines the characteristics of materials within products and components. It aims to be a ‘one stop shop’ for material information. A compilation of material passports would provide a detailed inventory of a building’s component materials and characteristics. These characteristics include physical properties such as dimensions, chemical properties such as lifecycle environmental assessments, biological properties such as decomposability, and material health such as impact on indoor air quality[1].

This approach enables more efficient maintenance and end of life activities as it would be easier to identify and reallocate or repurpose resources. However, reliable and standardised information[2] is critical for material passports to be useful and interoperable (comparable in different countries/regions and with other datasets).



Snapshot of the materials platform prototype
Source: https://www.bamb2020.eu/topics/materials-passports/

[1]https://www.bamb2020.eu/wp-content/uploads/2019/02/BAMB_MaterialsPassports_BestPractice.pdf
[2]https://www.bamb2020.eu/topics/materials-passports/standardization-tools/

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Circular building assessment (CBA)

CBA is a methodology to evaluate product and material resource flows during and beyond the lifetime of a built asset. It incorporates multiple lifecycle approaches to model aspects such as environmental impacts, financial costs, health consequences and social value[1]. Assessments can be for an element (such as a wall) or for a whole building. Outcomes include the quantification and comparison of 'business as usual' design approaches to circular building scenarios such as:

- reuse from the previous built environment
- design for future reuse via reversible building design
- the potential to transform, highlighting corresponding environmental and economic net benefits.

The CBA software prototype uses Building information Modelling (BIM) to extract and combine building and product data[2].

Data is collected across four different levels
Source: User Guide for CBA, http://www.bambcba.eu/Home/Downloads

[1]http://www.bambcba.eu/Home/About
[2]https://www.bregroup.com/buzz/circular-building-assessment-prototype/

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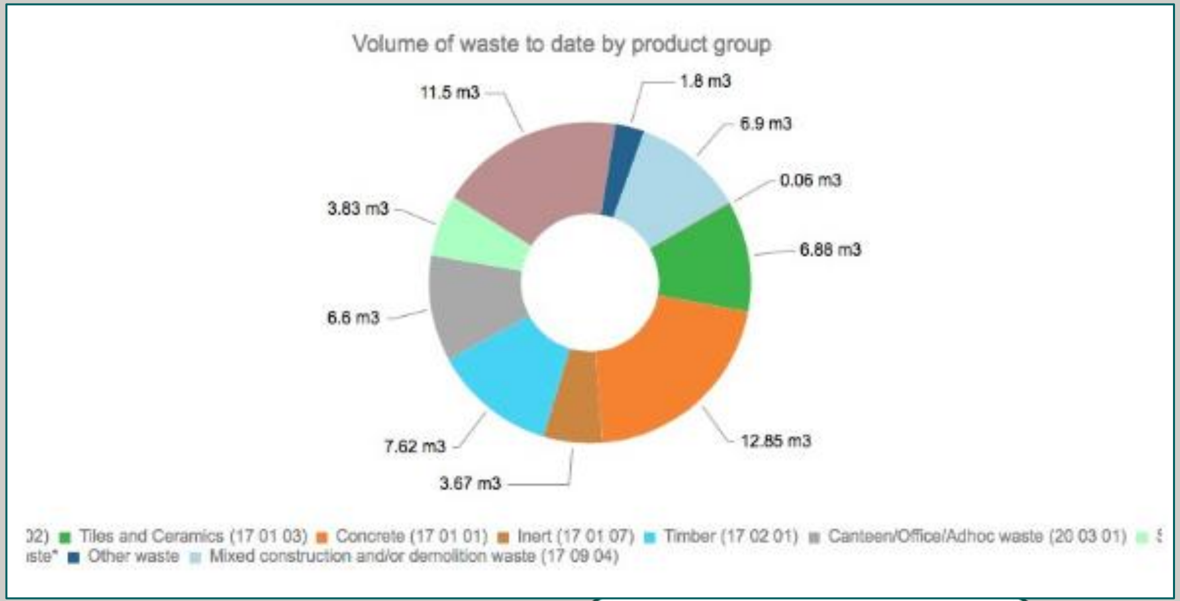
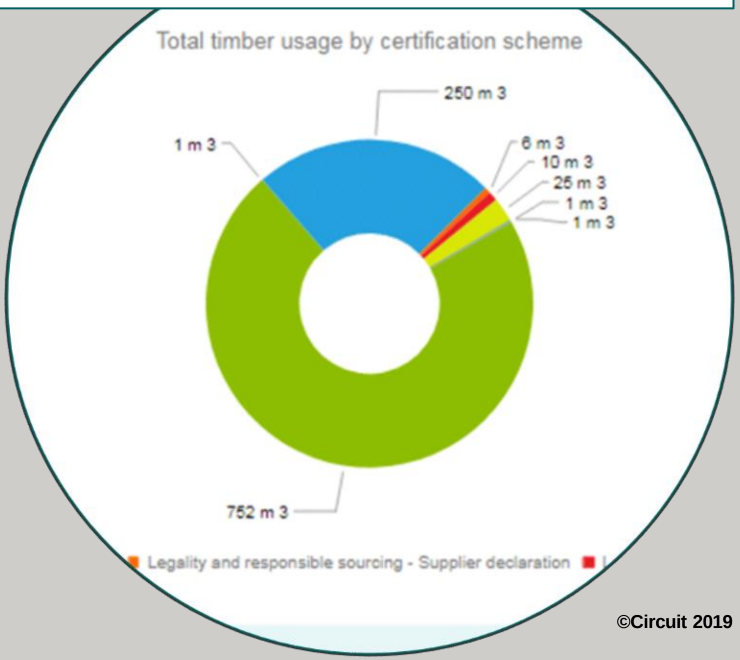
BRE SmartWaste

SmartWaste is a commercial platform that is widely used by project teams to monitor and record data on the quantities of various waste classifications arising from a project site. As part of the process, data is also collected on characteristics of the project (such as building type, works undertaken). More work could be undertaken to aggregate this data for quantifying typical materials released from various building types.

The top image shows an example from waste management, which provides waste types, amounts, recovery routes, etc. The bottom image shows materials management, which monitors certified and non-certified materials (Source: https://www.bresmartsite.com/products/smartwaste/)





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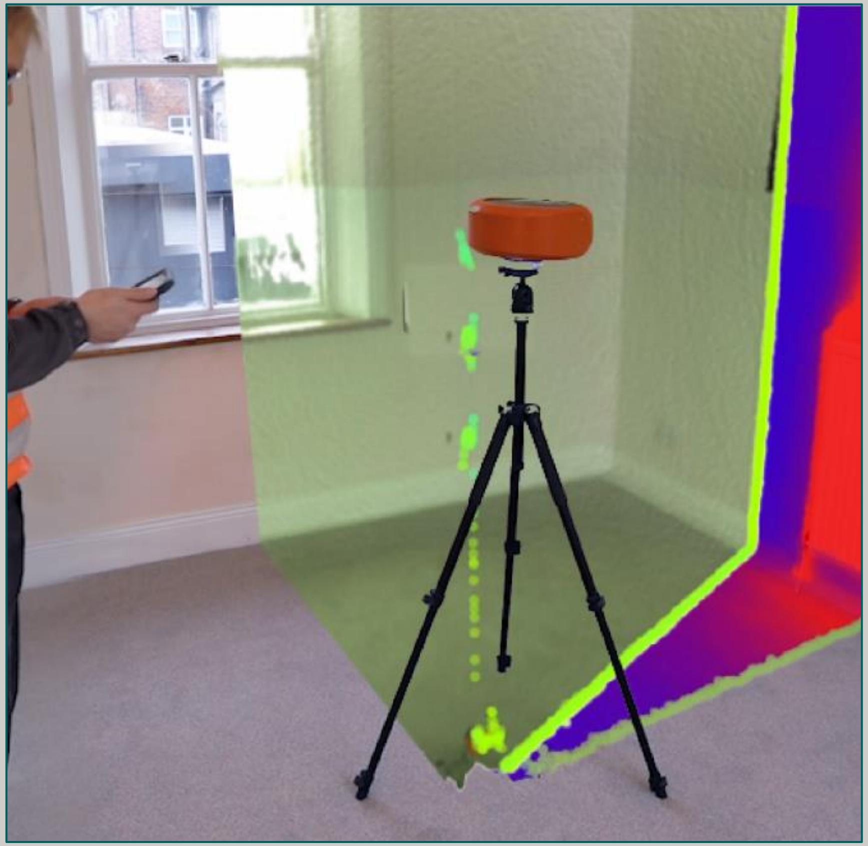
Building surveying technologies

Modern sensing and optical technological advances have enabled the automation of many surveying processes. This makes it easier, quicker and less disruptive to gather accurate building and infrastructure data. Furthermore, the incorporation of these technologies with unmanned aerial vehicles (UAVs) and robotics enables data capture from areas that may be unsafe or difficult to access.

Technologies include, but are not limited to:

- Laser scanning surveys using LIDAR (light detection and ranging) to create a point cloud (coordinates for each point of physical contact) which transfers spatial data to a 3D model.
- RADAR (radio detection and ranging) and ground penetrating RADAR surveys that scan for hidden or buried components.
- Digital terrestrial/aerial photogrammetry that creates detailed surface models.
- Electro-optical/infrared (EO/IR) cameras that detect performance issues and defects without physical disruption (thermography)
- Depth cameras that judge depth and distance in photography, enabling 3D reconstruction



Example: Q-Bot technological solution for stock condition surveys that automatically creates a digital record of the building and condition
Source: https://q-bot.co/landlords/stock-condition-survey

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Smart Data Capture

The incorporation of smart technologies such as sensors and tracking devices (RFID tags, QR codes, etc.), with physical components of the built environment can improve traceability by providing enhanced geographical and condition data. Distributed ledger technology (DLT), such as blockchain, is increasingly seen as a facilitator of traceability by creating an uncorruptible chain of information on material flow. Tracking devices can automatically collect data on building components and update ledgers and BIM models[1]. There are also novel ideas such as DNA-of-things (DOT), which stores data in nanometer silica beads that may be fused into various materials[2].

Overall, smart data capture facilitates an increase in collaboration and information sharing, which is an industry challenge. DLT can also be used to manage ownership and intellectual property rights in a transparent way, protecting stakeholders and increasing trust. However, a key challenge may be the cost of and willingness to add devices to each building component.

The crowdsourcing of data is also a promising direction. There is an emergence of citizen-generated building and infrastructure data shared on online platforms such as the World Urban Database and Access Portal Tools (WUDAPT)[3] and Colouring London[4].

[1]Koch et al (2020). A DNA-of-things storage architecture to create materials with embedded memory. Nature Biotechnology 38:39-43.
[2]Information on the possibilities in DLT and material traceability was obtained from Alistair Wilson, PhD candidate at University of Loughborough, through personal communications
[3]http://www.wudapt.org/ [4]https://colouringlondon.org/

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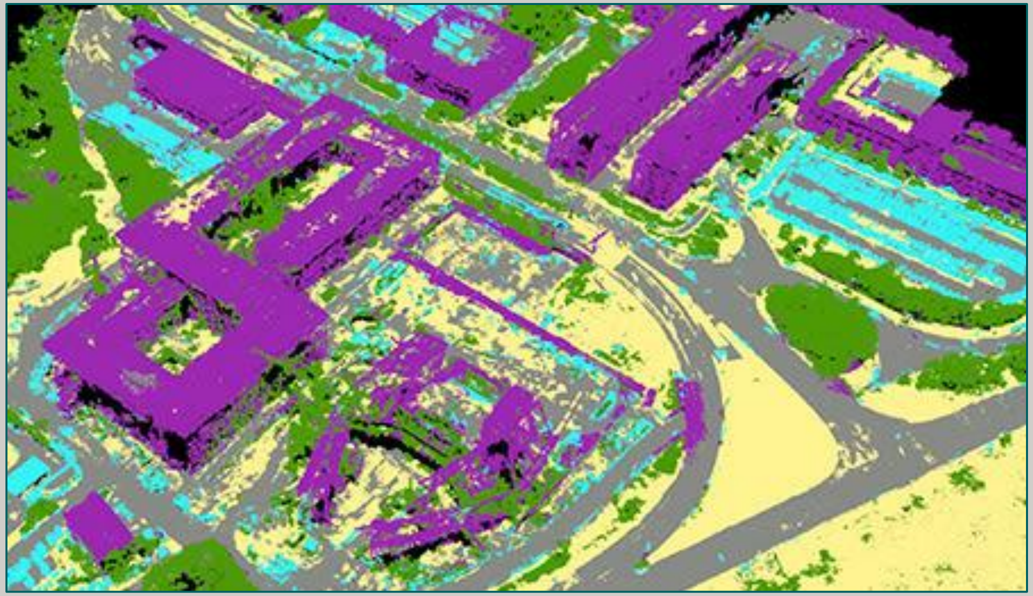
Machine Learning

Machine learning explores the study and construction of algorithms that can learn from, and make predictions about, data. Computer vision and pattern recognition use algorithms to find patterns and create classifications from large datasets.

The techniques can be incorporated with the previously mentioned building surveying technologies to extract data on the quantity and quality of various building and infrastructure types, materials, changes over time, etc.

The images show an example of the company Pix4D's automatic segmentation from imagery data – buildings are in purple, ground is in yellow, trees are in green, and human-made objects are in cyan (Source: https://www.pix4d.com/blog/construction-surveys-point-cloud-classification).



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Conclusions

State of the art on material flow data in the built environment

This document summarizes one of CIRCuIT's tasks that identified and assessed datasets with information on building material stocks and flows in the partner cities. Overall, data capture on building materials is fragmented and inconsistent which makes it challenging to accurately map material stocks and flows. There are varying levels of accessibility ranging from organizational operations held on private databases to easily extracted open data centralised by government. In some cases there is little transparency on data collection methodology and classifications with similar data using a range of units and formats.

There are existing datasets that can be combined to generate circularity insights but for most scenarios, supplemental information is required from individual reports and publications. This creates limitations with achieving reliable city-level calculations. Standardization, consistency and a more granular approach to data capture at the city-level is required. Integration is especially needed between planning and waste management such that materials can be cross-referenced along the value chain. Useful tools and methodologies are already being developed.

Building on this work, upcoming CIRCuIT tasks include recommendations for improving data capture and utilisation, the development of circularity indicators and the use of these insights to generate data from demonstration projects.

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CIRCuIT Circular Construction In Regenerative Cities

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