D2.1 Framework for circular interventions in the construction value chain

And its applications for multifunctional green roofs, façades and interior elements

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Framework for circular interventions in the construction value chain

And its application for Multi-functional Green Roofs, Façades and Interior elements

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Executive summary

The overall aim of BUS-GoCircular is to address and overcome the challenges of the stimulation of demand for green energy skilled workforce, along with hands-on capacity building to increase the number of skilled workforce across the value chain. But which skills does the workforce need to possess? Based on the different circular strategies and interventions that are being applied in practice we can map which occupations are involved within the implementation of these interventions. Based on this work (WP2.1) we can start mapping the different skills that are required for these different interventions (WP2.2).

A generic framework for Circular Economy interventions in the construction value chain and its first application has been developed for the BUS-GoCircular project. This framework is based on the eight Key Elements of the circular economy framework (tier 1). The result of this is a set of archetypical interventions that improve the energy performance of a building while applying circular key elements. The eight Key Elements consist of 25 more specific strategies (tier 2). For these 25 different circular strategy groups (tier 2), the professions, trades and roles that are involved with implementing each strategy have been mapped across five stages of the value chain: Plan, Procure, Construct, Operate, and End of Service Life.

This serves as the basis to provide an overview of the different roles that are required to implement such a strategy, from factory operative, over material scout, to material engineers. The framework has then been applied to the circular strategies relating to multifunctional roofs, façades and interior elements, including strategies evolving around energy efficiency. This application has been validated through interviews with relevant external stakeholders and experts from across the BUS-GoCircular project consortium.

List of acronyms and abbreviations

BIM: Building Information Model

CRM: Critical Raw Materials

EoSL: End of Service Life

KE: Key Elements

MGRFIE: Multi-functional Green Roofs, Façades and Interior Elements

RES: Renewable Energy Source

SME: Small and Medium-size Enterprise

WP: Work Package

Definitions

Circular economy: The circular economy offers the next progressive step in our economic model, taking over from the current linear 'take-make-waste' economy by seeking to extract the maximum value from resources in use and keep materials in circulation for as long as possible through processes like reuse, repair, remanufacture and recycling. The ultimate goal of a circular economy is to establish an ecologically safe and socially just operating space for humankind.

Critical raw materials: Those raw materials that are most important economically and have a high supply risk for the EU, as listed by the European Commission[1].

Key elements framework: The Key Elements (KE) framework is a conceptual framework of eight elements of circularity that can be applied at different intervention levels (for example, national, regional, sector, business, product, process, or material) towards a circular economy. The KE framework consists of three core elements and five enabling elements. Core elements deal with physical flows directly, whilst enabling elements deal with creating the conditions or removing barriers, for a circular transition[2].

The three **core key elements** are:

1. **Prioritise regenerative resources:** Ensuring that renewable, reusable, non-toxic resources are used in the manufacturing of built environment. Ensuring that all resources are used in an efficient way.

2. **Preserve and extend what is already made / Stretch the lifetime:** While resources are in-use, maintain, repair and upgrade them to maximise their lifetime and give them a second life through take back strategies when applicable.

3. **Use waste as a resource:** Utilise waste streams as a source of secondary resources and recover waste for reuse and recycling.

The five **enabling key elements** are:

[1] DG Grow, 2021. https://ec.europa.eu/growth/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en
[2] Circle Economy, 2021. https://www.circle-economy.com/resources/the-key-elements-of-the-circular-economy-framework

1. Design for the future: Account for the systems perspective during the design process, to use the right materials, to design for appropriate lifetime and to design for extended future use.

2. Collaborate to create joint value: Work together throughout the supply chain, internally within organisations and with the public sector to increase transparency and create joint value.

3. Rethink the business model: Consider opportunities to create greater value and align incentives that build on the interaction between products and services.

4. Incorporate digital technology: Track and optimise resource use and strengthen connections between supply chain actors through digital, online platforms and technologies that provide insights.

5. Strengthen and advance knowledge: Develop research, structure knowledge, encourage innovation networks and disseminate findings with integrity.

Multi-functional Green Roofs, façades and Interior Elements: combine multiple functions in order to maximise the return of a roof or façade (the front part or exterior of a building). Interior elements are considered insofar as they support the functions of buildings' roof and façade. Each function can be denoted its own colour[3]:

- Green roofs or façades incorporate vegetation (such as moss, grass, shrubs, trees, etc.) and offer space for nature and horticulture. This can contribute to cooling and insulating properties, improve local air quality and biodiversity.
- Blue roofs or façades provide water retention and harvesting functions, for example, to delay stormwater runoff, reduce flooding and offer opportunities to reuse rainwater to water interior plants.
- Yellow roofs or façades generate sustainable energy, for example to power or heat the building with solar panels, thermal collectors, or wind turbines.
- Red roofs or façades make use of buildings' exterior space for social functions, such as roof-top playgrounds, bars or cinemas.

[3] Building Changes, 2021. https://www.multifunctioneledaken.nl/kleursysteem/;
Rotterdam Municipality, 2021. https://www.rotterdam.nl/wonen-leven/multifunctionele-daken/

- Grey roofs or façades provide technical functions such as inlet-outlet heat recovery ventilation, chimneys and natural light.

Strategy group: A set of strategies corresponding to each of the eight key elements of circularity. Strategy groups include more detailed descriptions of strategic interventions and actions to implement the key elements in practice. These are in turn underpinned by more than 75 detailed strategies for the circular economy.

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1. Introduction

1.1. Circular approaches to construction and the built environment

The built environment has a significant impact on many sectors of the economy, on jobs, on quality of life and the natural environment. It is responsible for a significant share of environmental degradation: from soaring greenhouse gas emissions, to intensive resource use and biodiversity decline. Buildings are often developed without regard to the ecosystems of which they are a part. And in our civilisation's history, we have built a lot: the mass of human-made things, from pavements to apartments to phones, now outweighs all natural biomass, such as our oceans, trees and animals[4].

During their lifetime of operation, buildings are responsible for 40% of EU final energy consumption, and 36% of greenhouse gas emissions[5]. The embodied emissions from the rest of the building life cycle are estimated to contribute at least a further 10%[6]. More than 50% of all extracted materials are attributed to buildings[7], while construction is responsible for around 2.3 billion tonnes of waste generated per year in the EU, or 36% of the total[8].

Building with, as opposed to over, nature has long been perceived as more of a burden than an opportunity. And this is a shame—because by working smartly together, we can build a better living environment for people, for nature and for the built environment sector itself. A built environment that is less wasteful, more resourceful and that supports nature.

A greater uptake of circular approaches means generating less waste, facilitating greater reuse and recycling of products and materials at the end of each service life, and helping to reduce the environmental impacts and life cycle costs.

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[4] Elhacham, E., Ben-Uri, L., Grozovski, J. et al. Global human-made mass exceeds all living biomass. Nature 588, 442–444 (2020). https://doi.org/10.1038/s41586-020-3010-5

[5] Impact Assessment for the amendment of the Energy Performance of Buildings Directive, SWD(2016) 414.

[6] IEA, 2019. Material Efficiency in Clean Energy Transitions reports estimates that 10-20% of EU buildings' CO_2 footprint represents the embodied carbon.

[7] DG GROW, 2021. https://ec.europa.eu/growth/industry/sustainability/buildings-and-construction_en

[8] Eurostat, 2018. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics

Which circular approaches can be applied to the built environment? The key elements of the circular economy framework offers insights in the varied options that we will see being implemented, now and in the future.

2. Approach

2.1. The key elements of the circular economy framework

The principles of a circular economy concern designing out waste, regenerating ecosystems and keeping items in use. Decoupling the economy from material flows—improving the rate of resource productivity faster than the economic growth rate—is also a consistent guide. By evolving with the growing number of applications of circular economy principles, and consolidating these strategies across thematic areas, Circle Economy's Key Elements Framework (KE)[9] renders the elements of the circular economy salient and serves as a basis to derive contextual strategies and interventions.

The Framework consists of:

- **Core Elements:** Activities directly handling product or material flows; and uniquely,
- **Enabling Elements:** those that remove obstacles for core actors.

The origins

In an effort to define a common language for the circular economy, Circle Economy does continuous research on the terms and definitions used in practice and in the literature. Based on a mapping, interpretation and in-depth review of the various terms and definitions used by over 20 organisations —NGOs, government agencies, academia, consultancies, and others— Circle Economy identified eight key elements that define the majority of terms linked to the circular economy. As such, the KE framework of the circular economy has been developed as a generic framework that can be applied to any industry sector or value chain.

[9] Circle Economy, 2020. https://www.circle-economy.com/resources/the-key-elements-of-the-circular-economy-framework

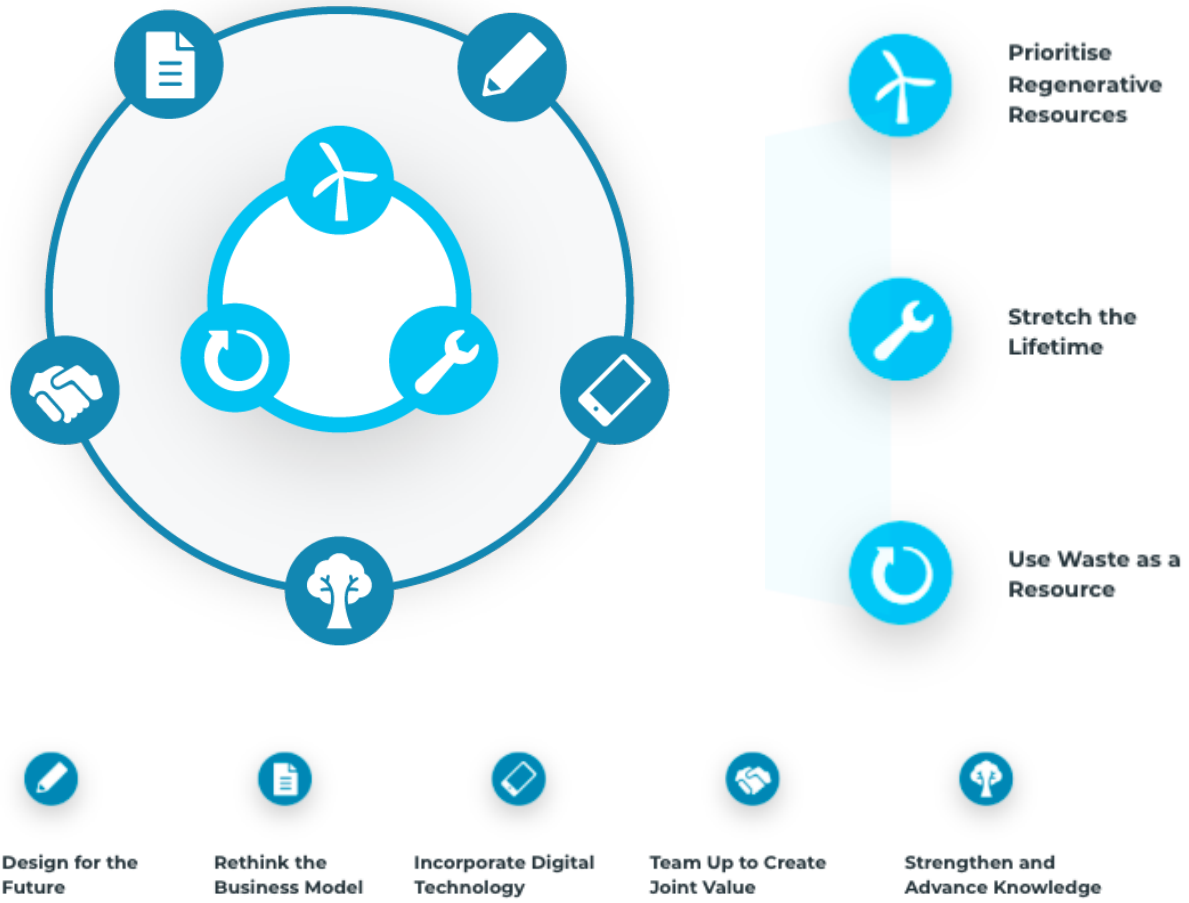

Figure 1: The key elements of the circular economy framework visual

Strategy groups

For each element, both core and enabling, a corresponding set of 25 strategies, or strategy groups, are identified. These provide further description of strategies to implement the key elements on a practical level. The first key element, *prioritise regenerative resources*, for example, is broken down into three strategy groups: regenerative materials, regenerative water, and regenerative energy. These strategies in turn form the building blocks for identifying circular strategies for the construction sector and applying this general framework to the case of multi-functional green roofs, façades and interior elements.

2.2. Mapping job roles to implement circular strategies across the construction value chain

Construction value chain

The built environment value chain consists of different roles within the different stages of the value. Figure 2 shows the different phases of the built environment value chain.

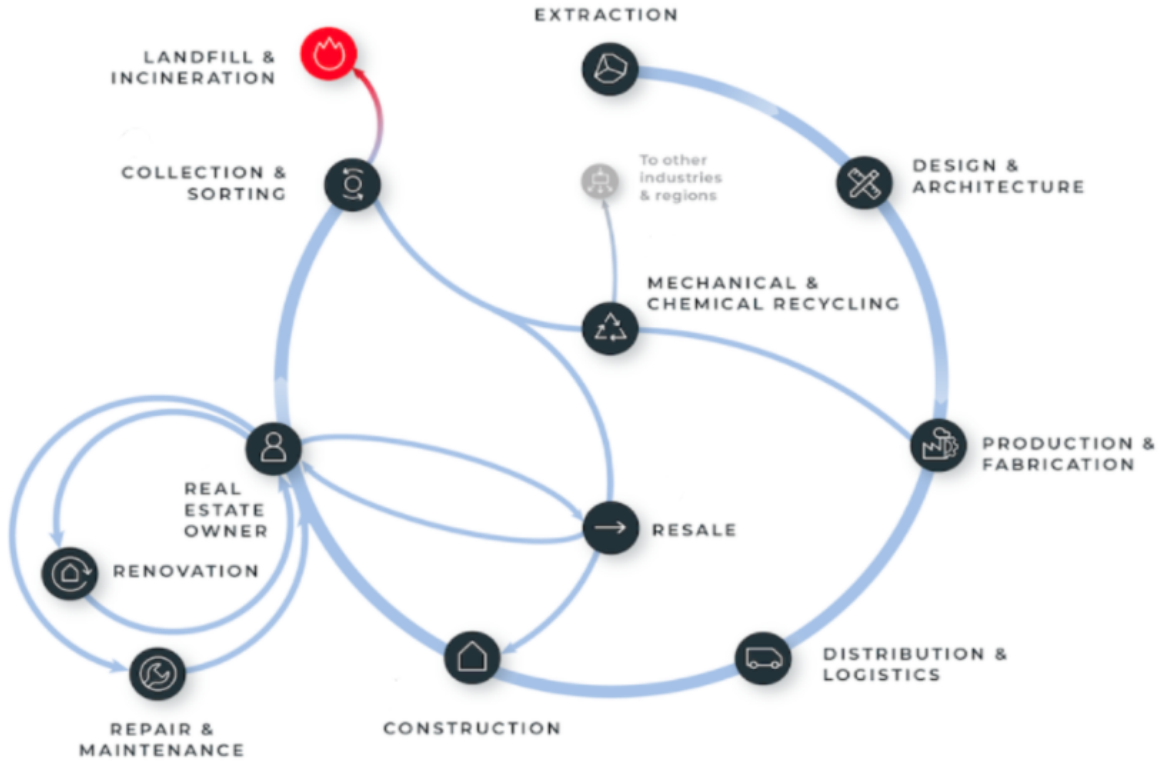

Figure 2: The built environment value chain as used in Circularity Gap Report Built Environment Netherlands (unpublished)

Based on research by Roland Berger[10] we have condensed these to the following five stages:

1. **Plan:** design and commission (new and existing buildings);

[10] Schober, K-S (2021). It's time for construction to embrace the circular economy. Roland Berger. https://www.rolandberger.com/en/Insights/Publications/It%E2%80%99s-time-for-construction-to-embrace-the-circular-economy.html

2. **Procure / source:** materials, products and services (new and existing buildings);
3. **Construct**: build and fit-out (new buildings);
4. **Operate**: maintain, renovate and manage (existing buildings); and
5. **End of service life (EoSL)**: Deconstruct, dismantle, repurpose, sort and process.

To this, a further stage is added that captures the important role played by industry and public actors in setting ambitions and standards for the built environment. This stage, which sits outside of the value chain, greatly influences attitudes to building projects that, in the linear economy, are typically concerned with ensuring compliance while limiting costs up to the point of delivery.

6. **Governance:** ambition setting through policy and standards, and compliance.

For the purpose of mapping the job roles involved in implementing the identified circular strategies, roles associated with governance are integrated within the planning phase.

Job roles, professions and trades

To account for differences in naming conventions for job titles across countries and companies, the work builds on previous EU projects such as PROF/TRAC[11], Construction Blueprint[12] and Train4Sustain[13] to define different work-fields and the reference professions and trades within these. See appendix 1 for the full overview. The different reference professions and trades have been plotted, for the different circular interventions across the five stages in the value chain above.

Important to note that self-employed workers in the construction value chain and those working in SMEs that share the same reference profession or trade with their counterparts in larger firms may adopt tasks across multiple stages in the value chain that are conducted by specialists or operational staff in larger firms, or contracted out on larger-scale projects. A carpenter on a small renovation project, for example, is likely to be responsible for procuring the materials to carry out their work while also being responsible for dealing with waste materials. On a larger project, the procurement of materials and waste management may instead be handled by specialist staff.

[11] Prof-Trac: http://proftrac.eu/open-training-platform-for-nzeb-professionals.html
[12] Construction Blueprint: https://constructionblueprint.eu/
[13] Train4Sustain: https://train4sustain.eu/services

For both the general and applied framework, the reference professions and trades are used to map out the job roles involved in carrying out the work activity to implement the identified circular strategies.

3. Results

3.1. General framework for circular interventions in the construction value chain

From a review of 16 projects and strategies developed to implement and accelerate the circular economy for the built environment, this project has identified more than 50 different circular interventions that are specific to the construction value chain, and mapped them onto the KE framework. The framework thus now has an extra layer of depth which can help a broad range of stakeholders that work in the built environment to check for inspiration and identify other possible actions.

The tables below present an overview of the 25 different Circular Strategy groups and how they can and are being applied within the built environment. Important to note, circularity within the built environment is developing quickly and new technological circular approaches might be developed that are not included within the framework. The approach to circular construction does however provide an in-depth overview of the different circular strategies and interventions that are currently being applied.

Table 1: Core key elements and their application to circular construction

Table 2: Enabling key elements and their application to circular construction

Table 1: Overview of the key core elements, their applications to circular construction and affected professions and trades (reference codes)*

Core key element	Strategy group	Approach to circular construction	Plan*	Procure	Construct	Operate	EoSL
Prioritise regenerative resources	Regenerative materials	- Build with sustainably sourced wood - Build with hemp, seaweed, cork, bamboo, earth, etc. - Use alternative (bio)forms of concrete - Reduce size of building envelope and floor space e.g. through shared and multifunctional building spaces - Use of reusable or recyclable materials, e.g. glass, plasterboard - Use prefab to avoid material losses on site - Use non-toxic construction materials, e.g. alternatives to anti-flame retardants used on wood - Avoid the use of CRMs for construction e.g. natural rubber - Lightweight design and 3D printed building materials - Build with sustainably-sourced agricultural residues, e.g. straw / sheep's wool as insulation	AR MS ME CE EE UP AM C	MS PM	C CE ME SS Br II FM BA	FaM C CE ME SS Br II FM FW R WI BA	DeA DeL
	Regenerative water	- Use grey water for certain applications (e.g. washing) - Use Plant-Based Biofilters to Purify Household Wastewater - Sustainable water technology - Collect and reuse water in humid interior areas, e.g. cellars - Cascading of water	AR P EI	PM PD	P Gd R EI	DA P Gd	DeA DeL
	Regenerative energy	- Producing renewable energy through eg. installation of solar panels / heat pump - Measures to more efficiently use the energy in the house (eg. smart solutions to spread demand throughout the day) - More efficiently use of thermal energy (e.g. insulation and draught-proofing, ideally with reused/recycled materials)	AR EE EL	MS PM	RESI RWT II	DA RESI RWT II	DeA DeL

		- Reduced floor space through less living space/co-housing, tiny homes, multifunctional building spaces - Reduced operational energy use associated with more intensive buildings use - Using building materials with lower thermal conductivity coefficient = lower energy consumption of buildings - Increasing energy efficiency by insulation of buildings					
Preserve and extend what is already made / Stretch the lifetime	Maximise lifetime of products in-use	- Digital tracking of materials in order to maximise lifetime of products through BIM: It provides proactive insight into vital systems and can model the effects and changes affiliated with upkeep, repair, or improvement. In a practical sense, it delivers real-time insight into how facilities currently operate, right down to the system level. - Building lifetime extensions, especially through renovation - Preserving built structures with regular checks and repair - Share information how to repair and maintain building components eg. DIY painting	ME CE EL AR SC	MS	P EI RESI RWT ACHP VI RM	RM DA	DeA DeL
	Maximise lifetime of products after-use	- Upgrade, expand and repurpose eg. through use of (digital) marketplaces - Find new and/or alternative ways of already existing buildings that are currently not in use	AR SC	MS PM	n/a	n/a	DeA DeL
	Maximise / optimise lifetime of biological products	- Maximise, preserve and manage biological products on site (eg. green roofs, walls) - Clean and prevent contaminated land - Source high-quality biological materials with suitable properties for long lifetime (eg. type of crops, residues or biomass stock)	AR SC	n/a	n/a	RM DA EE	DeA DeL

Use waste as a resource	Valorise waste streams - closed loop	- Use demolition materials as a resource for new buildings - Source demolition materials - Save resources by using local demolition materials in construction of new structures	AR CE SC	MS PM DeA	n/a	n/a	DeA DeL CE SC AR
	Valorise waste streams - open loop	- Use demolition materials as resource for other purposes/products - Separate waste created during construction - Reuse construction materials in infrastructure - Recycle PVC cables into floors	AR CE SC	MS PM	n/a	n/a	DeA DeL
	Energy recovery from waste	- Burn construction biomass waste that cannot be reused to win the energy - Process construction biomass (eg wood) streams into high-value added streams (eg. biochemicals, biomethane etc.) - Recover energy from non-recyclable waste - Recovering the waste from on-site materials production processes (e.g. cement, tar)	n/a	n/a	C HS	n/a	DeA DeL

**Note: reference codes for professions and trades are provided in table 5, Appendix 1. n/a: no reference professions/trades involved in implementing the circular strategy at that stage in the value chain.*

Table 2: Overview of the key enabling elements, their applications to circular construction and affected professions and trades (reference codes)*

Enabling key elements	Circular strategy	Approach to circular construction	Plan*	Procure	Construct	Operate	EoSL
Design for the future	Design out waste	- Reduce the consumption of total raw materials needed for construction, e.g minimise the use of steel for buildings - Design for resource efficiency for all life cycle stages (eg. minimum energy consumption during use phase) - 3D print buildings to design out waste	ME CE EL AR	ME CE EL MS	Br II FM FW R WI BA	DA BEC SC	DeA DeL
	Design for cyclability	- Design so that products and installations are easy to repair - Legolise/modularise the construction of buildings / infrastructure to facilitate disassembly and reuse. - The manufacture and assembly of building components and modules in a factory, which are then transported and installed onsite; offsite and pre-fab construction - Apply non-toxic biodegradable materials/products - Apply material passports to enable more timely upgrading and life-time extension	ME CE EL AR BS HS	ME CE EL MS	ME EL FM P FW R BA	P FM R FW BA EI VI RESI RWT RM	DeA DeL
	Design for durability	- Design for flexible and adaptive use e.g. flexible partition walls and systems to adapt to changing needs of occupants - Design for longevity	ME CE EL AR	ME CE EL MS	ME EL FM P FW R BA	RM	DeA DeL

Collaborate to create joint value	Industry collaboration	- Regional collaboration (e.g. aimed at improving procurement) - - Regional construction networks and digital marketplace with the focus on industry collaboration - Develop high-value, circular product applications though collaboration - Public and private parties jointly develop the knowledge with which the timber construction chain (architects, constructors and contractors) is helped and protected - Employ regional innovation public bodies to collaborate with private actors towards research, development and market uptake of key circular technologies - Collaborate across the value chain to achieve the goal of designing out waste (industrial ecology)	ME CE AR	PM	HS	HS	HS
	Customer / consumer collaboration	- Reverse logistics collaboration - Educate homeowners on sustainable construction and renovation options - Provide consumers with reliable data on the environmental footprint of their choices (eg. ecolabelling) - Get feedback from consumers in order to improve the product	PD	n/a	n/a	n/a	n/a
	Government collaboration	- Establish circular construction and demolition criteria - Public private partnerships	PA	PA GPPA	PA	PA	PA
	Internal collaboration	- Circular procurement within the built environment training - Apply the circular strategies within the firm to serve as an example	n/a	n/a	n/a	n/a	n/a

	Community collaboration	- Develop high-value, circular product applications though community collaboration - Locally source materials - Create new job opportunities by applying circular strategies in the value chain	n/a	n/a	n/a	n/a	n/a
Rethink the business model	Product business models	- Electrical products / boilers / heat pumps as a service - Interior features (e.g. partition walls) as a service - Offer different leasing and ownership models to provide access rather than ownership (e.g. Rockwool strategy) - Prefabricate building modules - Incentivize the renovation of currently unused buildings	PD	n/a	C CE ME BS Br II FM FW R WI BA	RM	DeA
	Service business models	- Offer construction repair services as a service - Product as a service model for parking spots	PD	n/a	C CE ME BS Br II FM FW R WI BA	RM	DeA

Incorporate digital technology	Data and insights	- Optimise maintenance, demolition, and recovery through digital tracking of materials through digital tracking of materials. - Develop and use material and buildings passports	DA	DA	DA	DA	DA
	Digital platforms	- Regional construction digital marketplace - Digital marketplace for parking spots	DA	DA	DA	DA	DA
Strengthen and advance knowledge	Education and Curriculum	- Circular Procurement within the built environment training - Incorporation of circular strategies, archetypal interventions and case studies to the curriculum	n/a	n/a	n/a	n/a	n/a
	Knowledge Management	- Develop circular construction and demolition criteria - Measure the impact of buildings and building materials	n/a	n/a	n/a	n/a	n/a
	Research and Development	- Develop high-value, circular product applications through research and development - Generate knowledge on applied circular strategies in construction sector by case studies and meta studies - Analyse effectivity, barriers and successes of applied circular strategies	n/a	n/a	n/a	n/a	n/a
	Communication and awareness	- Educate homeowners on sustainable construction and renovation options - All parties in the construction industry must be aware and be informed of the developments in the field of environmental costing models and CO2 taxes - Raise awareness about recycled construction materials, to break the unwillingness to use it for new construction - Motivate consumers to favour repurposing and renovation over new buildings	n/a	n/a	n/a	PA BEC FaM BO AM	n/a

**Note: reference codes for professions and trades are provided in table 5, Appendix 1. n/a: no reference professions/trades involved in implementing the circular strategy at that stage in the value chain.*

3.2. Applied framework for circular interventions for multi-functional roofs and façades

For testing its validity, the above framework is applied for the first time with a focus on the circular development of multifunctional roofs, façades and interior elements (MGRFIE), including strategies evolving around energy efficiency. For this we have applied the general framework interventions to multifunction roofs, façades and interior elements where relevant. This list was reviewed and validated in collaboration with construction industry and MGRFIE experts within the consortium, and by external partners beyond. Where needed generic circular interventions that were/were not relevant for MGRFIE were added or removed.

Table 3: Core key elements and their application to MGRFIE

Table 4: Enabling key elements and their application to MGRFIE

Table 3: Overview of the key core elements, their applications to MGRFIE and affected professions and trades (reference codes)*

Core key element	Strategy group	Approach to MGRFIE	Plan*	Procure	Construct	Operate	EoSL
Prioritise regenerative resources	Regenerative materials	- Construct roofs and façades with sustainably sourced wood - Construct with other regenerative materials eg. hemp, straw - Construct roofs and façades with alternative forms of concrete - Integrate multi-functionally into Build by making use of roof-space and façade - Use reusable / recyclable materials for the construction of MGRFIE (e.g. glass, plasterboard) - Using prefab elements for the construction of MGRFIE - Using non toxic construction materials for MGRFIE - Avoiding the use of critical materials for MFRIE - Lightweight design and 3D printed Build materials for MFRIE - Minimize material use with 3D printing - Vertical gardens as part of façades and interior walls - Wood or thatch/straw panels for rainscreen cladding and insulation on façade	AR FDE CO	MS PM	FDE C BS SS FM CE ME WI BA	DA P EI VI RESI RWT RM II WI BS SS	DeAs
	Regenerative water	- Rainwater harvesting on roofs (or façades) to be used for certain applications eg. washing, toilets - Using Plant-Based Biofilters in façades, green roofs, or interior plant walls to Purify Household Wastewater - Incorporate functions that substitute for materials associated with building's water e.g. retention reduces need for wide drainage pipes, and water reuse for toilets/plants reduces use of chemicals and other materials to treat water. - Stimulate the sponge function for peak moments of water of roofs and façades	FDE CE AR	PM PD MS	Gd R	DA P Gd	DeA P

		- Stimulate the cooling of the city/building with slowly releasing rain water					
	Regenerative energy	- Producing renewable energy through eg. installation of solar panels on roofs and façades - Enable more efficient use of thermal energy e.g. insulation and draught-proofing, ideally with reused/recycled materials with green roofs and faces - Incorporate functions that substitute for materials associated with building's energy e.g. domotics (home automation) to control sun blinds or night time ventilation, cooling effect of rainwater retention; - Enable reduced floor space through multifunctional façades and roofs - Using building materials with lower thermal conductivity coefficient for green roofs, façades and interior elements - Using green roofs and façades to insulate buildings - Installation of organic solar panels - Solar thermal heating system on roof - Bioenergy façades (installed glass panels on the façades with algae that produce biomass and heat) - Keep the the city cooler by applying green roofs	FDE CE AR ME EL	PM PD MS	EI VI RESI RWT II	RESI RWT EI	DeA RESI RWT EI
Preserve and extend what is already made / Stretch the lifetime	Maximise lifetime of products in-use	- Applying digital predictive maintenance sensors for MGRFIE - Renovate with the use of MGRFIE to extend lifetime of current building stock - Extending the lifetime by regular checks and repair - Share information how to repair and maintain green roofs, façades and interior elements eg. cleaning of solar panels - Use of durable, resistant material (e.g. natural slate) for rainscreen cladding extends lifetime of façade - Design MGRFIE for maximization of value over time eg.	ME CE EL AR SC	MS	P II EI RESI RWT VI	RM R FW Gd WI R RM FW Br	R FW

		flexible use within time; change in function				BA FM	
	Maximise lifetime of products after-use	- Use (digital) marketplace for products or components of the green roof, façades and interior elements - Directly use 'after-use' materials for the construction of MGRFIE elements, skip physical storage stage	AR SC	MS PM	n/a	n/a	DeA
	Maximise / optimise lifetime of biological products	- Keeping green roofs in a healthy state maximising green / biodiversity impact - Keeping living walls (interior, exterior) in a healthy state maximising green / biodiversity impact - Apply green roofs and façades to clean contaminated land or water	AR SC	n/a	n/a	Gd RM	DeA
Use waste as a resource	Valorise waste streams - closed loop	- Reuse construction demolition materials for the construction of MGRFIE - Use locally sourced deconstruction materials as an input for MGRFIE - Take back schemes for MGRFIE components and products	AR ME CE SC BA	MS PM DeA	n/a	n/a	DeA DeL
	Valorise waste streams - open loop	- Use recycled materials from other industries for construction of MGFRIE (examples below) - Innovative façades using recycled materials from other industries, eg. PET bottles - Recycled textiles as roofing materials to catch water.	AR ME CE SC	MS PM	n/a	n/a	DeA
	Energy recovery from waste	- Recover energy from non-recyclable waste coming from MGRFIE - Process MGRFIE biomass into high-value added stream	n/a	n/a	HS C	n/a	DeA

**Note: reference codes for professions and trades are provided in table 5, Appendix 1. n/a: no reference professions/trades involved in implementing the circular strategy at that stage in the value chain.*

Table 4: Overview of the key enabling elements, there applications to circular construction and affected professions and trades (reference codes)*

Enabling key element	Strategy group	Approach to MGRFIE	Plan*	Procure	Construct	Operate	EoSL
Design for the future	Design out waste	- Reduce consumption of total raw materials needed for construction of MGRFIE - Design for resource efficiency throughout the different life cycles of the MGRFIE products (eg. water drainage, energy optmiaslisation) - 3D print façades and interior elements	AR ME CE EL	ME CE EL MS	C R Br II FM FW R WI BA	DA BEC SC	DeA
	Design for cyclability	- Design MGRFIE product so that they are easy to repair - Use modularity in construction of façades, roofs and interior elements to facilitate disassembly and reuse. - Use materials that can be reused at the end of the life cycle of MGRFIE - Use materials for the façades, roofs and interior elements that are non-toxic and biodegradable - Apply material passport to enable cyclability in the future	AR ME CE EL	ME CE EL MS	C R ME EL FM P FW R BA WI Br	R FW FM WI Br P BA P EI VI RESI RWT RM	DeA
	Design for durability	- Design durable and repairable materials for all MGRFIE components	AR ME EL	ME EL AR	C R FM P	R EI WI FW	DeA

					FW R BA WI EI Br	FM Br RM RESI RWT	
Collaborate to create joint value	Industry collaboration	- Collaborate to apply and improve circular procurement processes of MGRFIE - Collaborate regionally to design out waste during construction and after the end of life cycle of MGFRIE - Regional construction networks and digital marketplace with the focus on industry collaboration either focussed on MGRFIE or broader - Connect public (regional innovation bodies) and private parties to deepen knowledge and incentivise practical collaboration on circular applications of MGRFIE	AR ME CE EL	PM	HS	HS	HS
	Customer / consumer collaboration	- Educate owners of MGFRIE on the best use to achieve longevity of products - Educate homeowners on the benefits of installing MGRFIE - Get feedback from consumers in order to improve the product - Apply and provide consumers with reliable data on the environmental and social footprint of their MGRFIE products - Get consumer feedback on MGRFIE products	PD	n/a	n/a	n/a	n/a
	Government collaboration	- Establish criteria for MGRFIE - Incentivise the use of e.g. green roofs with different programs and economic instruments (subsidies)	PA	PA GPPA	PA	PA	PA

	Internal collaboration	- Internal training and awareness building about urgency, challenges and solutions of circular MGRFIE - Apply the MGRFIE in the firm to serve as an example and to provide the employees first hand experience with the product	n/a	n/a	n/a	n/a	n/a
	Community collaboration	- Engage with environmentally conscious inhabitants of apartment buildings to find solutions for installing a multifunctional green roof or a façade - Involve community in job opportunities of MGRFIE	n/a	n/a	n/a	n/a	n/a
Rethink the business model	Product business models	- Façades as a service - Technical installations as a service eg. heat pump - Interior features (e.g. partition walls) as a service	PD	n/a	C R	RM	DeA
	Service business models	- Repair as a service for MGRFIE	PD	n/a	C R	RM	DeA
Incorporate digital technology	Data and insights	- Connect roofs to sewage systems to avoid flooding them - Sensor technology in green façades to facilitate water flow from roof when needed - Drones to scan/image frontages of buildings e.g. FaSA - Use and apply the data and insights from MGRFIE material pasport	DA	DA	DA	DA	DA
	Digital platforms	- Marketplaces for MGRFIE products and components - Material and product passports for MGRFIE e.g. Cirlinq-platform	DA	DA	DA	DA	DA
Strengthen and advance knowledge	Education and Curriculum	- Train for circular strategies for any part of the MGRFIE value chain - Incorporate circular strategies and case studies for MGRFIE in the curriculum	n/a	n/a	n/a	n/a	n/a

	Knowledge Management	- Common language about circularity and interventions in MGRFIE - Disseminate knowledge of circular MGRFIE - Share Impact measurement of MGRFIE	n/a	n/a	n/a	n/a	n/a
	Research and Development	- Research, development and innovation of MGRFIE - Analyse barriers and success factors of MGRFIE buildings during 'operate' phase to provide input for further development - Generate knowledge on applied circular strategie in MGRFIE by case studies and meta studies - Developing new prototypes of MGRFIE and improve tailored solutions with the focus on effectivity, multifunctionality and circularity	n/a	n/a	n/a	n/a	n/a
	Communication and awareness	- Educate homeowners of the positive environmental effects of MGRFIE, e.g. effect of green roofs on temperature and air quality. - All parties in the MGRFIE construction industry must be aware and informed of developments in the field of environmental costing models and carbon taxes of MGRFIE - Share and communicate about the benefits of circular MGRFIE	n/a	n/a	n/a	PA BEC FaM BO AM	n/a

**Note: reference codes for professions and trades are provided in table 5, Appendix 1. n/a: no reference professions/trades involved in implementing the circular strategy at that stage in the value chain.*

4. Future development and applications

The frameworks included herein provided a basis for informing the required skills and current skills needs associated with the different roles needed to fulfill circular strategies (task 2.2), and the development of circular construction qualifications framework (task 2.3). Together the tasks in WP2 enable the consortia to design a train-the-trainer programme in WP3 that addresses the application of the frameworks developed, capacity building activities in WP4 to provide formal and informal skill recognition on the qualification developed, and the national implementations in WP5.

Based on additional feedback from applying the framework and other stakeholders applying the various circular strategies and interventions the framework can be further refined in future. Furthermore, the lessons from applying the circular construction framework to the case of multifunctional green roofs, façades and interior elements provides valuable lessons on how the framework can also be applied to other more specific circular built environment related focus areas, such as circular heat pump and ventilation installations.

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APPENDIX 1 - Reference professions and trades

Table 5: Workfields, references professions and trades within the work fields with their corresponding reference codes

Work field	Reference professions and trades within the work field	Reference code
Ambition setting and governance	Policymaker / Policy advisor	**PA**
	Green Public Procurement (GPP) advisor	**GPPA**
Asset management	Asset manager Real estate investor	**AM**
Urban planning	Urban planner	**UP**
Architecture	Architect Interior architect Architectural technician Designer	**AR**
	Landscape architect Green roof / green façade designer	**LA**
Civil engineering	Civil engineer Construction engineer Structural engineer	**CE**
	Façade design engineer	**FDE**
Electrical engineering	Electrical engineer ICT engineer Building automation engineer	**EL**
Mechanical engineering	Mechanical engineer Energy engineer	**ME**
Environmental engineering	Environmental engineer	**EE**
Building management	Facility manager	**FaM**
	Building operator	**BO**
	Data analyst BIM programmers, BIM designer Software engineer 3D image technician / engineer	**DA**
Construction management	Cost engineer Project manager and coordinator Quality control and assurance Quantity surveyor	**C**
	Health and safety (H&S) advisor H&S inspector Site supervisor	**HS**

Surveying	Site surveyor Land surveyor	**SS**
	Building surveyor	**BS**
Financing and procurement	Procurer / purchasing manager Procurement officer	**PM**
	Project developer	**PD**
	Material scout	**MS**
Energy performance	Building energy consultant Energy assessor	**BEC**
Sustainable building	Sustainability consultant Sustainability assessor	**SC**
Conservation	Conservation Officer Conservation scientist / ecologist	**CO**
Construction - building	Bricklayer Stone-layer, cutter and mason	**Br**
	Insulation Installers	**II**
	Carpenter Joiner	**FM**
	façade worker Plasterer	**FW**
	Roofers	**R**
	Gardener (roof and façade) Interior planter / landscaper Arboriculturalist / Horticulturist	**Gd**
	Window installer / glazer	**WI**
	Wood manufacturer and finisher Pre-fabricated building assembler Truss assembler	**BA**
Construction - Technical installations	Plumber	**P**
	Electrical installer and technician	**EI**
	Renewable energy systems installer (electric)	**RESI**
	Renewable energy systems installer (thermal)	**RWT**
	Heat pump installer	**HPI**
	Ventilation installer Air conditioning installer	**VI**
	Repair and maintenance operative Maintenance planner Safety maintenance operative	**RM**
Demolition and deconstruction	Demolition / deconstruction labourer Demolition / deconstruction supervisor	**DeL**
	Site analyst Deconstruction auditor Urban miner	**DeA**

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