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ANALYSIS OF CIRCULAR ECONOMY SYSTEMS AND STRATEGIES IN THE CONSTRUCTION SECTOR

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CAP. 1 - INTRODUCTION

This analysis was developed within the Interreg VI-A Italy-Slovenia Programme, for the project Circular.Buildings. The main aim of the research conducted by DPIA Uniud has been the analysis of the construction supply chains management systems.
The study focused on how circular economy principles can be integrated in the building life-cycle stages; furthermore, the attention turned toward the cross-border context in order to high-light gaps and possibilities to improve the circularity approach in the local construction sector.

The construction industry has the greatest impact on the environment: firtstly, it is worldly responsible for the utilisation of over the 40% of resource utilisation [1], with the specific consumption of 60% of the total amount of aggregates, 20% of metals [2] and 25% of virgin woods [3]. It also contributes, between 30% and 40%, to the CO2 emissions [2] and to the consume of global energy and water, for about, respectively, 40% and 16% [3]. However, the greatest impact is related to the production of huge amounts of construction and demolition waste, which accounts for about 40% of global solid waste [1], while for the European Union the rate is 36% [4].
These data show the need for a change of approach in the construction industry to limit resource consumption and waste generation: over the past decades, the introduction of the circular economy (CE) paradigm in the industry has proven to be an optimal way to achieve significant environmental improvements.

The Ellen Macarthur Foundation (EMF) [5] defined CE as “a system where materials never become waste and nature is regenerated”, in which “products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting” and that “tackles climate change and other global challenges, like biodiversity loss, waste, and pollution, by decoupling economic activity from the consumption of finite resources”. EMF has schematised the concept perfectly with the Circular Economy Butterfly Diagram (Figure 1): it clearly distinguishes the biological cycle, in green, for biodegradable materials, and the technical cycle, in blue, for artificial products.

This economic system contrasts with the traditional linear economy, based on the “take-make-waste” scheme, and involves resources moving on closed-loops governed by three basic principles, known as the “3Rs”, Reduce, Reuse and Recycle, which allow their efficient management and to always retain their best possible value; in order to do that, other Rs principles have been introduced to define a “9Rs” framework, that are Refuse, Rethink/Repurpose/Redesign, Repair, Refurbish, Remanufacture and Recover, partly mentioned in the EMF definition [6]. The opportunities for waste avoidance can therefore be

reclassified into three levels, with a decreasing degree of circularity from the first to the third, allowing the alignment with the EU waste hierarchy [7]:
- a first level of preventive action, which includes the principles of Refuse, Reduce and Rethink;
- a second level of product retention and extension of its lifespan, also with possible interventions, which includes Reuse, Repair, Refurbish and Remanufacture;
- a third level, as an extreme solution and the least circular, which seeks to maximise the value of materials at their end-of-life stage through Recycle and Recover.

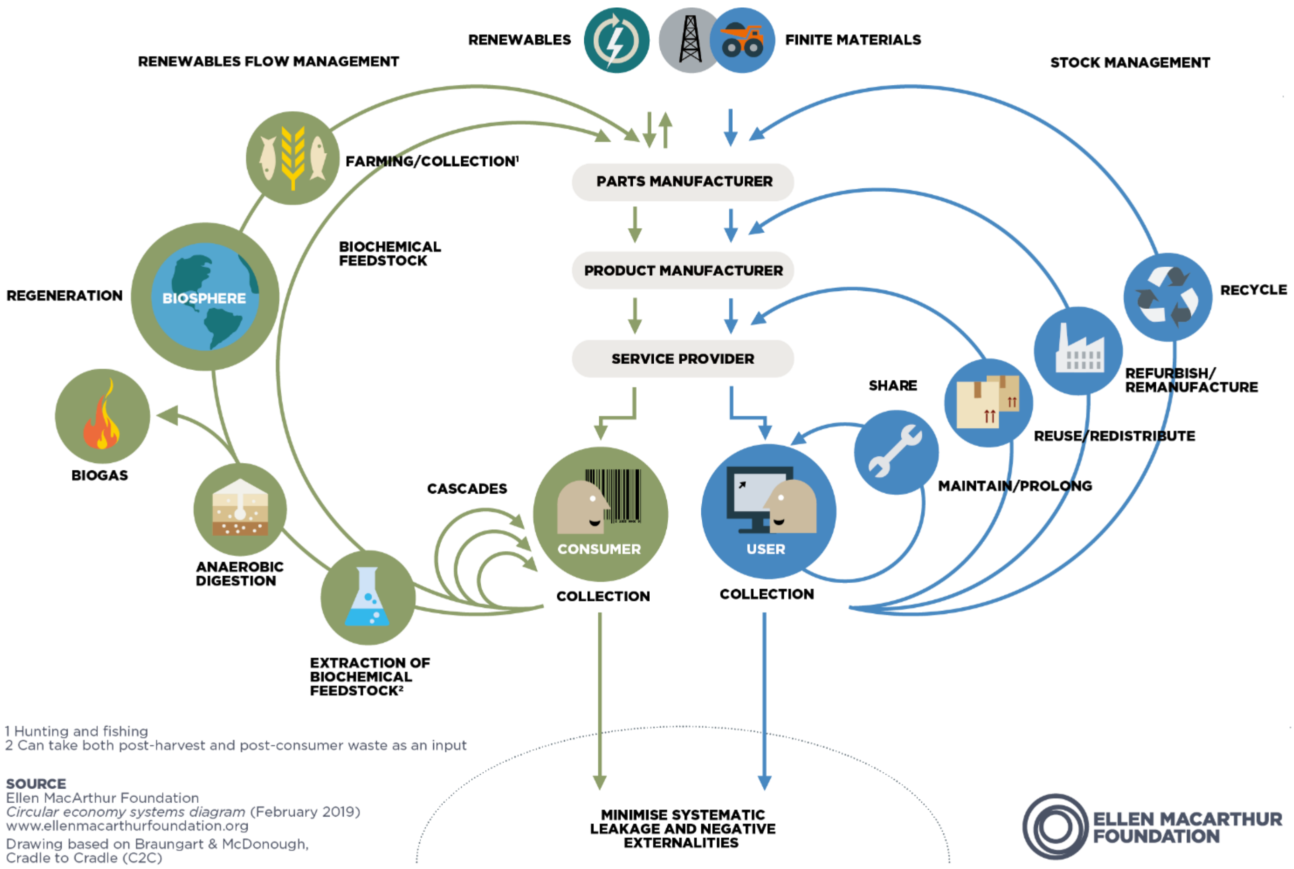

Figure 1: Circular Economy Butterfly Diagram [5]

To achieve improvements in the sustainability of the construction industry, it seems clear that the principles of the 9Rs need to be implemented, but always considering all the phases of the building life cycle, as defined for the Life Cycle Assessment in UNI EN 15978 in Figure 2. The targets for this specific sectors remain like generic CE ones [8]:
- narrowing resource use through improved and efficient planning, design, construction, use and management of buildings;
- slowing resource use by prolonging materials, components and whole buildings lifetimes;
- closing the loop excluding landfilling in favour of reuse and recycling.

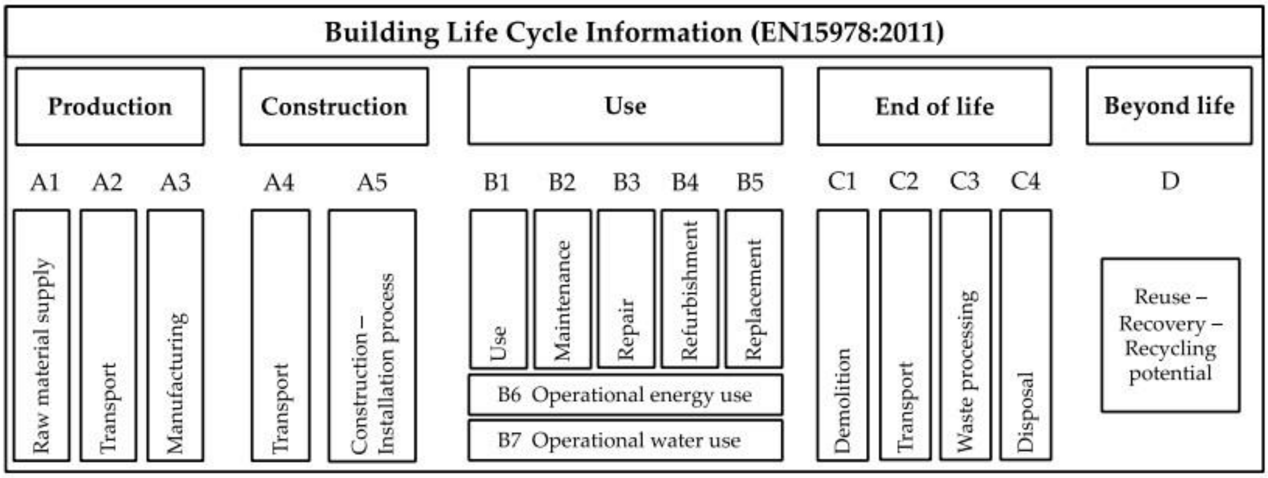

Figure 2: Building Life Cycle Phases (UNI EN 15978)

We can thus speak of "circular building": this type of building can be so-called when "is developed, used and reused without unnecessary resource depletion, environmental pollution and ecosystem degradation", "is constructed in an economically responsible way and contributes to the well-being of people and the biosphere" and in which "technical elements are demountable and reusable, and biological elements can also be brought back into the biological cycle". [9]

Although from this definition the concept appears very simple, a look, at the same time, to all the stages of the building life cycle, shows that the issue is much more complex: in fact, the entire construction supply chain must be involved in the circular transition in order to realise its full potential, and the problem lies in its extremely fragmented and articulated nature, among countless different stakeholders. The concept of a circular supply chain to date has been explored by several studies, however its implementation is not as widespread as it requires a radical change in the way processes are managed in the construction industry: it would be necessary for all entities involved along the building life cycle to have an adequate technological capacity, be willing to actively collaborate with each other and share the same circularity perspective.

In response to this problem, this analysis aims to investigate the management systems, the strategies and the tools that can be adopted to ensure a transition from a traditional linear supply chain to a circular one.

Using the vast literature accessible for the DPIA partner Uniud via academic research databases such as Scopus and Science Direct, a global scouting of virtuous systems/good management practices in circularity for the construction industry was carried out following the approach described below.

In accordance with the role entrusted to the Uniud partner and the expected results for the Circular.Buildings project, this report presents:

1. a summary of the literature evidence on the management systems of the construction supply chain, with a focus on the philosophies considered to have the greatest impact on the transition to circular supply chains and whose applicability in the Italian and Slovenian context is considered possible, such as industrial symbiosis, reverse logistic, cradle-to-cradle concept, etc;

2. a global literature scouting to identify the best circularity practices that can be easily and effectively introduced within the cross-border construction supply chain, with the subsequent production of summary sheets providing descriptions and practical information for the project's target stakeholders;

3. an analysis of the cross-border building stock to identify the most common existing building types and the interventions needed for them, and how identified best practices can improve their sustainability and circular management;

4. a selection of ongoing or recently concluded European projects focused on circularity in the construction sector, with particular attention to those in which Italian or Slovenian partners are involved in order to identify gaps in relationship with the best practices identified in the global context.

CAP. 2 - CIRCULAR CONSTRUCTION SUPPLY CHAIN MANAGEMENT

In order to better understand how the principles of the circular economy can be introduced into the construction supply chain, a meta literature review was conducted. The aim was to obtain a small number of papers that were themselves reviews about the circular supply chains in construction industry, as this topic is already highly debated and wide-ranging in terms of the issues it involves. From their reading, drivers were identified to extend the circular paradigm throughout the supply chain and, subsequently, practices and strategies for each stage of the supply chain.

2.1 - LITERATURE REVIEW

The selection of the papers of interest started in November 2024, with the last update in March 2025, always within the Scopus database, chosen for the large number of resources available in it; the search criterion “limited to journal” for “source type” was used for better authority and reliability in the results. The main problem was to find a string of keywords for the search that would narrow the field and obtain papers as relevant as possible to the purpose of the review: the combination ("construction" OR "build*" OR "built") AND "circular economy" AND "literature review" AND "supply chain" was therefore chosen.
Again, in order to improve the specificity of the results, the search for this string was restricted within article title, abstract and keywords: 81 papers were obtained in this way; the application of the limitation to English language articles resulted in the exclusion of only one article. From an initial analysis of the titles and keywords suggested by the author of each paper, all texts whose focus was not the building supply chains or particular circularity philosophies applicable to them were excluded, reducing the number of relevant articles to 27; of these we proceeded to read the abstract, eliminating a further 3 because they were not very indicative for the purpose of our research. The selection phases are outlined in

Figure 3.

Already from reading the abstracts of the different papers, the selection appears satisfactory, as it includes both texts with a broader view, as well as more specific towards circularity practices applicable to supply chains, so that we can provide a picture as complete as possible on the subject, in accordance with our purpose.
Looking at the publication dates of the articles, the topic is of recent interest: as can be seen in Figure 4, from 2023 onwards, there is a noticeable growth in the number of papers on the topic under analysis.

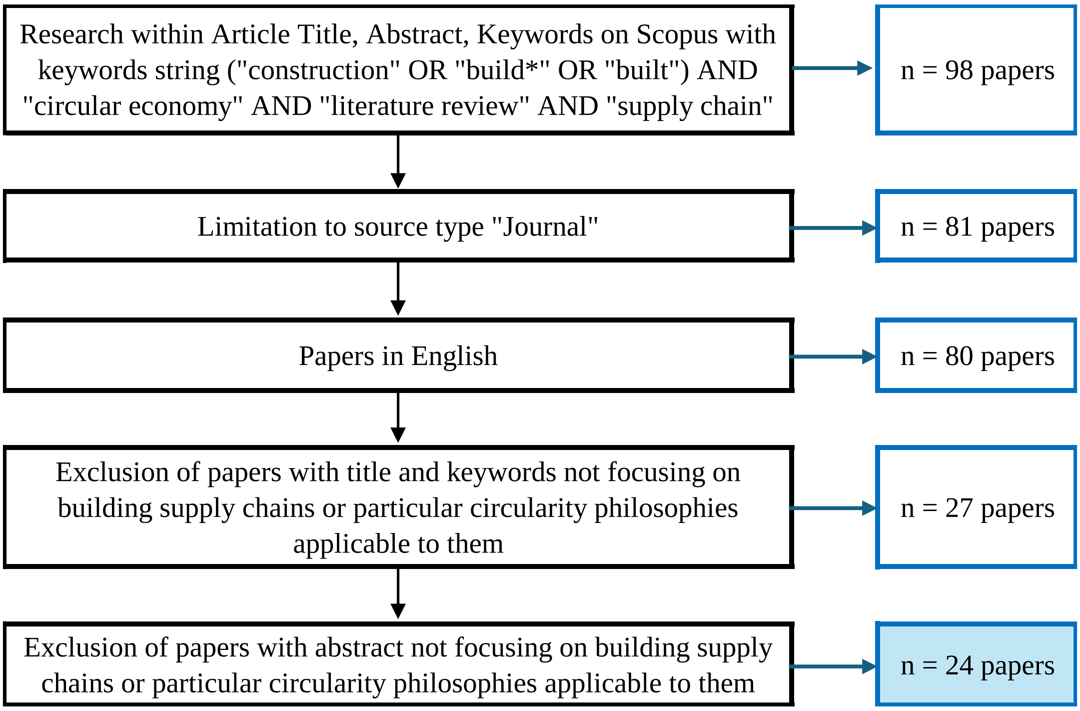

Figure 3: Papers selection path

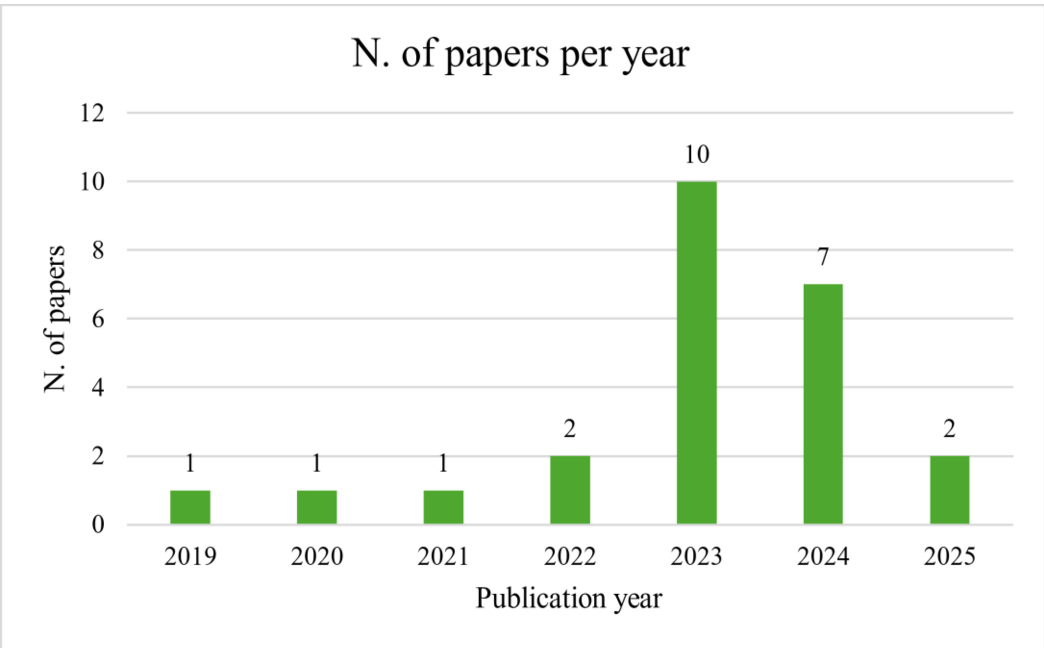

Figure 4: Number of selected publications per year

It should be noted that, for the papers selected as relevant, an additional search filter was tried to isolate any texts for which Italian or Slovenian authors appeared, but this search did not yield any results; we then tried to search within the full texts of the papers for direct references to applications or studies from the two states of interest, again yielding no matches. This does not mean that there are no publications on the subject in the literature, but only that in this sample of literature reviews analysed, no Italian/Slovenian studies or examples emerged that were particularly relevant according to the authors to be cited.
The following analysis of circular supply chains in the construction sector will present ways in which EC can be implemented in management systems that are not explicitly linked to the cross-border context, but which can be included in the same, as well as in any other global context, as its universal applicability is recognised by the experts themselves.

Shishehgarkhaneh et al. [10] define the supply chain as a network of parties transporting commodities, services, payments, and information from a supplier to a client; in the particular context of the construction sector, as already mentioned, the issue is even more complex because for each building, the supply chain spans numerous stakeholders, multiple functions and all phases of the building life cycle, from the design one, to the end-of-life (EoL) scenario. The transition from a linear to a circular supply chain requires a shift from a cradle-to-grave to a cradle-to-cradle approach, in which, after the EoL phase, if suitable, building components or materials can be directly reused or recycled for new projects: to the phases of the traditional construction supply chain, i.e. Design, Manufacturing (o Production), Construction (or Installation), Maintenance, Operation, two more are integrated, Demolition and/or Deconstruction [8].

For each phase, the stakeholders are numerous, as also depicted in Figure 5, but the participants most involved in the circular process are the client, designers (architects and engineers), contractors and sub-contractors, supply and distribution companies, demolition companies and recycling plants [11].

Firstly, the focus will be on circularity practices acting on the entire supply chain, i.e. design philosophies of the supply chain and typical tools for its management, while best practices for each phase of the building supply chain will be highlighted later. The strategies are presented here separately, but we must emphasise that the transition to the circular supply chain requires the combination of all of them to exploit their full potential.

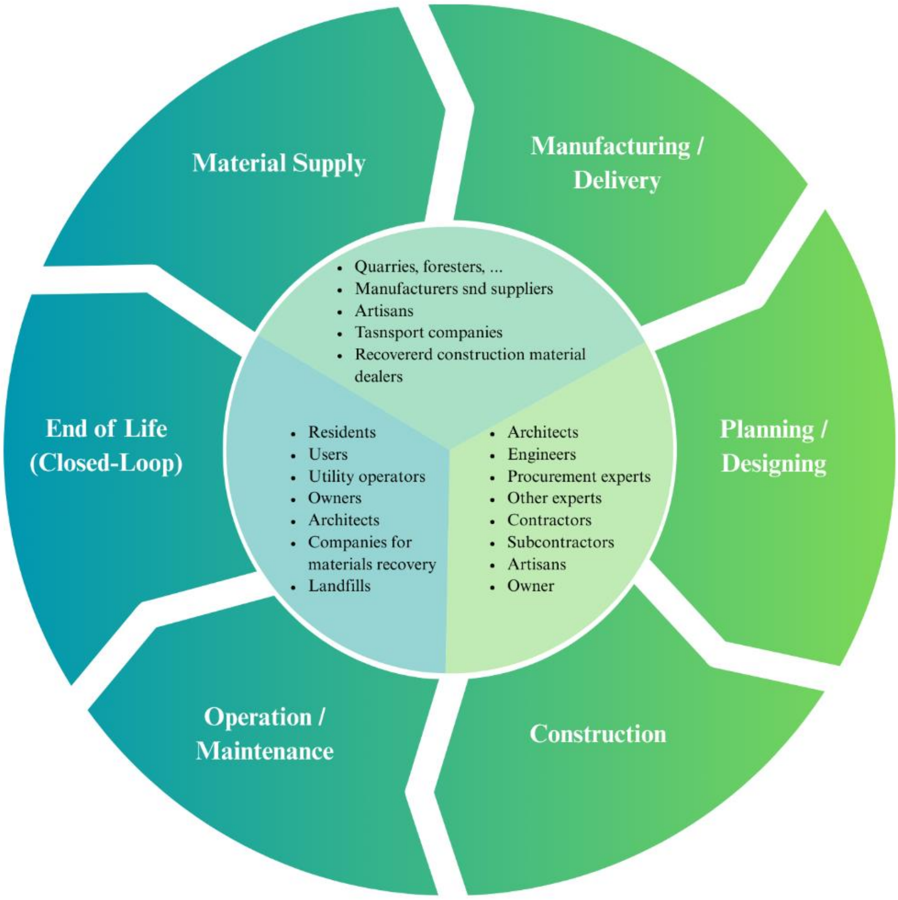

Figure 5: Circular construction supply chain phases and stakeholders (elaboration inspired by [12])

2.2 – SUPPLY CHAIN CIRCULARITY DRIVERS

The first circularity strategy that can be adopted in the management of a building supply chain is the **integration of reverse logistic (RL) with traditional forward logistic (FL)** creating a circular logistic, to guarantee a closed-loop system and minimizing the leak of resources; by Ding et al. [13] logistics is defined "as the process of planning, executing, and controlling efficient material and product flows, as well as relevant information through the construction project life cycle, in both directions: FL, from the point of material extraction to the in-use phase of construction projects, and RL, from the end-of-use of projects or products to the point of resource value recapturing or proper disposal". In the specific case of the construction sector, RL is best delineated as "the entire process of collecting construction and demolition waste (CDW) from CDW production divisions for recycling, processing, remanufacturing, and re-selling to recapture the value of the CDW or ensure its proper treatment … giving "life" back to a building that has lost its value through renovation and reuse".

Figure 6 provides a simple and comprehensive outline of how the integration of FL and RL should take place in order to ensure circularity in construction, with an indication of the actors involved in the different phases, as well as the practices and tools that ensure better management of the entire supply chain. We must emphasise the close cooperation that must exist between the stakeholders involved: a key role is played by planners, designers and suppliers of building materials and components in the upstream chain, as their choices determine whether or not they can go down the downstream chain, instead of having to dispose directly in landfills [14].

The reverse supply chain can be of two types, closed-loop or open-loop: the former occurs when the product, at the end of its useful life, returns directly to the original production site, where it is eventually re-processed to become sufficiently high performing to be reused, either with the same function or with a new one; this approach is much less widespread than the latter, hence the term open-loop: in this case, the CDW does not return to the original manufacturer, but is usually used in other industries, allowing for more possibilities of use [15] . It is precisely in this context that adherence to a new philosophy of supply-chain circularity, the **industrial symbiosis**, is crucial: this has been defined by the United Nations Economic Commission for Europe (UNECE) as "the collaboration of different sectors to match the wastes produced by one with the raw material requirements of another". Such cross-sectoral collaboration allows a balanced flow of materials in the construction industry, but above all to find multiple options for the reuse and recycling of CDW and to introduce in buildings also materials from waste produced by other industries that would otherwise have to be disposed. In relation to this, it follows that, in order to have circularity in the construction sector, it is necessary that the same paradigm is spread to the various other industries [4].

Industrial symbiosis in this context is the best application of a broader philosophy, which in turn is central to the circular economy, namely **industrial ecology**: this approach involves developing production systems as if they were natural systems, in which the production of waste is in no way included; this complements what has already been said of the cradle-to-cradle (C2C) concept, but gives even greater relevance to the elimination of environmental impact that can be achieved by a systematic design and realisation of the building and its components, especially when using natural and/or compostable materials instead of more polluting solutions [16].

Just as we have said that collaboration between the different sectors is important, in order to best integrate circularity within the construction supply chain there must be maximum collaboration between the stakeholders of the different phases of the building life cycle: one of the most effective strategies to date for doing this is the **vertical integration of the various SC partners**, which envisages long-term collaboration and trust between the different professionals involved throughout the whole life of the project. In this way it is possible, for example, for the contractor to manage the flow of construction materials and machinery on the construction site and to ensure efficient handling on site, or to coordinate logistics operations in order to minimise transport means, fuel consumption and, consequently, carbon dioxide emissions [13].

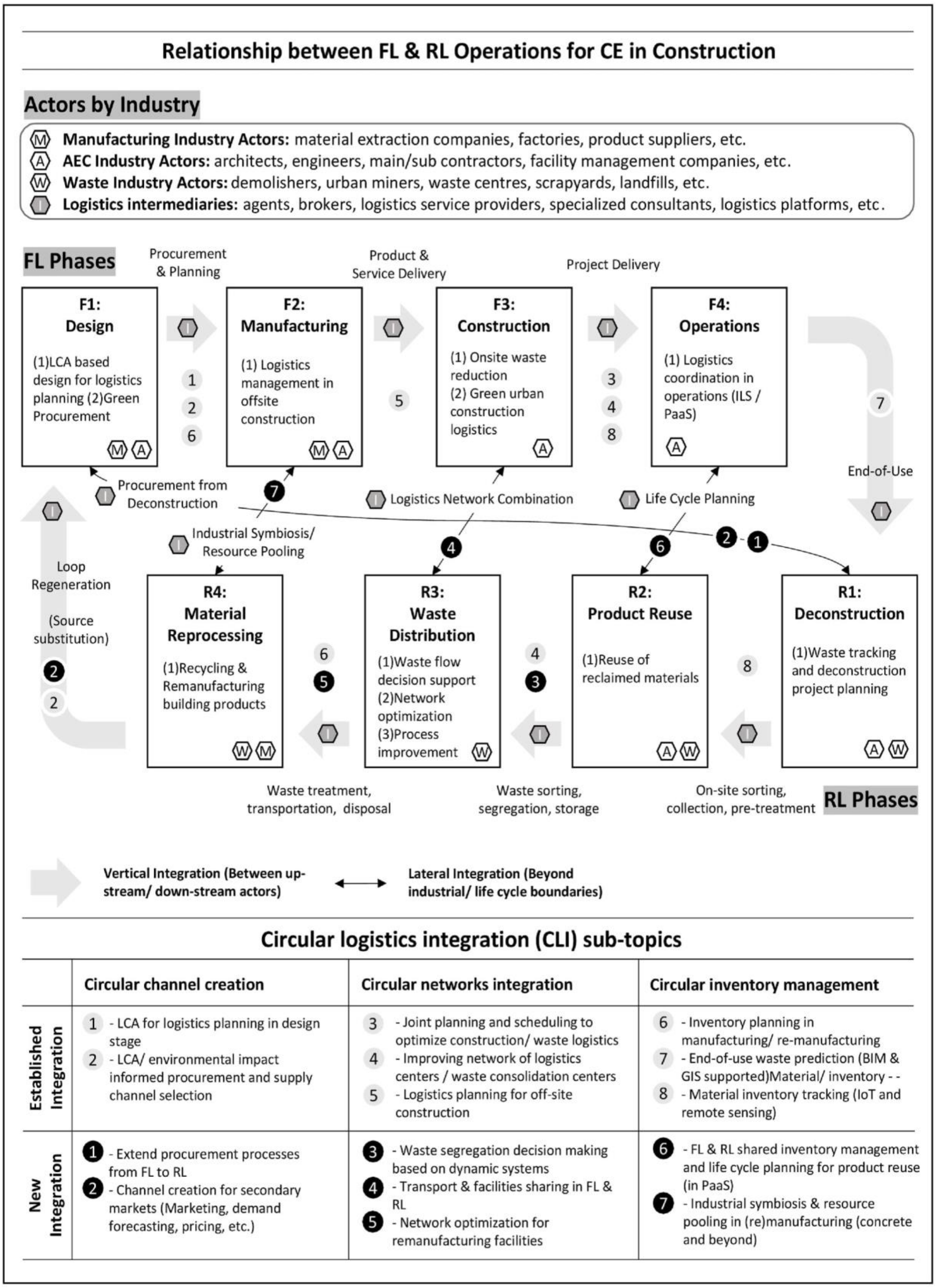

Figure 6: Circular logistics integration (CLI) framework for FL and RL operations in construction (taken from [13])

Vertical integration, however, in order to be feasible, needs tools that ensure a continuous **information sharing** between the stakeholders of the different stages of the supply chain: as stated by Wuni [13], this type of communication "enable the stakeholders and project team members to develop shared circularity goals, coordinate upstream and downstream circularity decisions and ensure that the functions of all members have a positive cumulative and complementary effect on the success of circular construction projects". The main problem is related to the complexity, but above all to the durability of the SC of a building: for example, the construction choices made in the design phase must be available in the deconstruction phase to ensure optimisation of operations and minimisation of waste production. Collaboration is the basis for planning approaches such as co-design (or participatory design), in which the continuous exchange of information allows the active involvement of all planners and clients to ensure that needs are met and to avoid integration problems between different parts of the project.

Currently, due to a lack of interest or knowledge in these practices, stakeholders tend to act autonomously, mostly to maximize their gains: this approach creates so-called structural holes, i.e. missing links between different figures involved in the building life cycle; one solution identified to bridge these gaps, is the introduction in the project of intermediatory actors called "**information brokers**": their role consists in facilitating the exchange of information, adapting, organising and interpreting it, until it becomes available from time to time to the actors to be brought into communication. Wijewickrama et al. [17] with their study identified three possible information brokers, i.e. **government**, professional communities and digital platforms. The first of the three is perhaps the most fundamental to making any construction supply chain, and consequently the entire sector, circular: its role consists of the introduction of laws and policies focused on a transition to the CE, but also of incentives, tax breaks and economic benefits that push stakeholders towards circular choices.

Professional communities are crucial for the training and education of designers and builders about circularity practices and ways of collaborative design and participation in projects; not only is it necessary for professionals to be constantly updated on new design techniques and technologies, but also and above all for new generations of stakeholders to learn from university and professional paths how to integrate CE principles into their work. Similarly, the role that professional communities can play in conducting public awareness campaigns capable of provoking a shift in the mentality of clients and builders, who today make decisions almost exclusively on an economic basis, should not be overlooked [2].

The third information broker are **digital platforms**, which play the triple role of sharing, connecting and collaborating: firstly, it is useful to improve the action of the other two brokers, as it allows the dissemination to as many professionals as possible of both government initiatives and professional communities. It also allows designers and companies in the construction sector to connect with each other to achieve co-design, but also from different sectors to improve industrial symbiosis and ensure waste minimisation; similarly, it can connect the CDW generating company with the companies involved in collection, transport, storage and reprocessing in order to continuously keep track of material flows, material processing, uses and properties [18]. In this respect, they can not only be used to store information on building materials, but also as platforms to create a secondary market with a view to circularity: contractors can either dispose of their waste or buy reprocessed building materials whenever they are needed from other contractors, manufacturers or recyclers at a low cost [17].

Cai and Waldmann [19], have proposed a new EC strategy capable of encapsulating the practices of collaboration, integration and connection described above: it is a **material and component bank**, described as "a manager who organizes the transfer of materials and components extracted from demolished or deconstructed structures to a new structure", from the global planning of demolition and deconstruction, the extraction and collection of recyclable and reusable materials and components, their assessment and improvement of the quality, with their later certification, allowing their selling in a factory or center shop of the bank. Figure 7 schematize the roles of the material and component bank in the key processes of sustainable construction: as can be seen, this makes it possible to coordinate numerous operations carried out on the building, and consequently the people involved, solving the problem of an excessively fragmented SC; The possibility of having the bank certified by the government in order to guarantee its validity is also not ruled out.

However, in order for SC management via a material and component bank to be possible, the support of **Building Information Modelling**, an universally considered an indispensable tool for the transition to a circular construction sector, is required. BIM can in turn be seen as a digital platform for the collaboration and management of information related to a building in all its life stages, in which all the stakeholders can participate: for example, it allows design through multi-parameter optimisation to achieve the minimisation of environmental impact or costs, or the creation of layouts for the decomposition of the building and the subsequent reuse of the entire building or parts of it.
As far as materials are concerned, there are many benefits to be gained from the implementation of a BIM model, including:

- obtain an inventory of embedded materials to evaluate the amount of waste that would be produced with the demolition of the building;
- confront different design options and associated construction schedule and their waste production and environmental impact [8];
- collect information on the path and performance of each component within material passports, both to facilitate its reuse in other buildings and to have quantifications of impacts useful for assessing the circularity of design choices [16].

Another digital technology that has recently been gaining ground to foster circular supply chain management, and which is also applicable to the construction industry, is **blockchain technology**: this is a system for decentralized computation and data storage where data security and reliability are ensured [8]; when an object is created in the database, it is associated with a token that, when authenticated by the recipient of interest, allows the history of the physical component to be traced entirely backwards. This technology is very useful for managing relationships between stakeholders, as well as for contracts between them: no company can unilaterally change the information entered into the blockchain network, so the authenticity of documents is always guaranteed, reducing disputes that in turn can cause delays and slowdowns in the SC [9]. Similarly, the blockchain technological platforms provide opportunities for "usage-based" insurances, which would ease the insurance constraints and increase the legal warranties of recycled and reused materials [8].

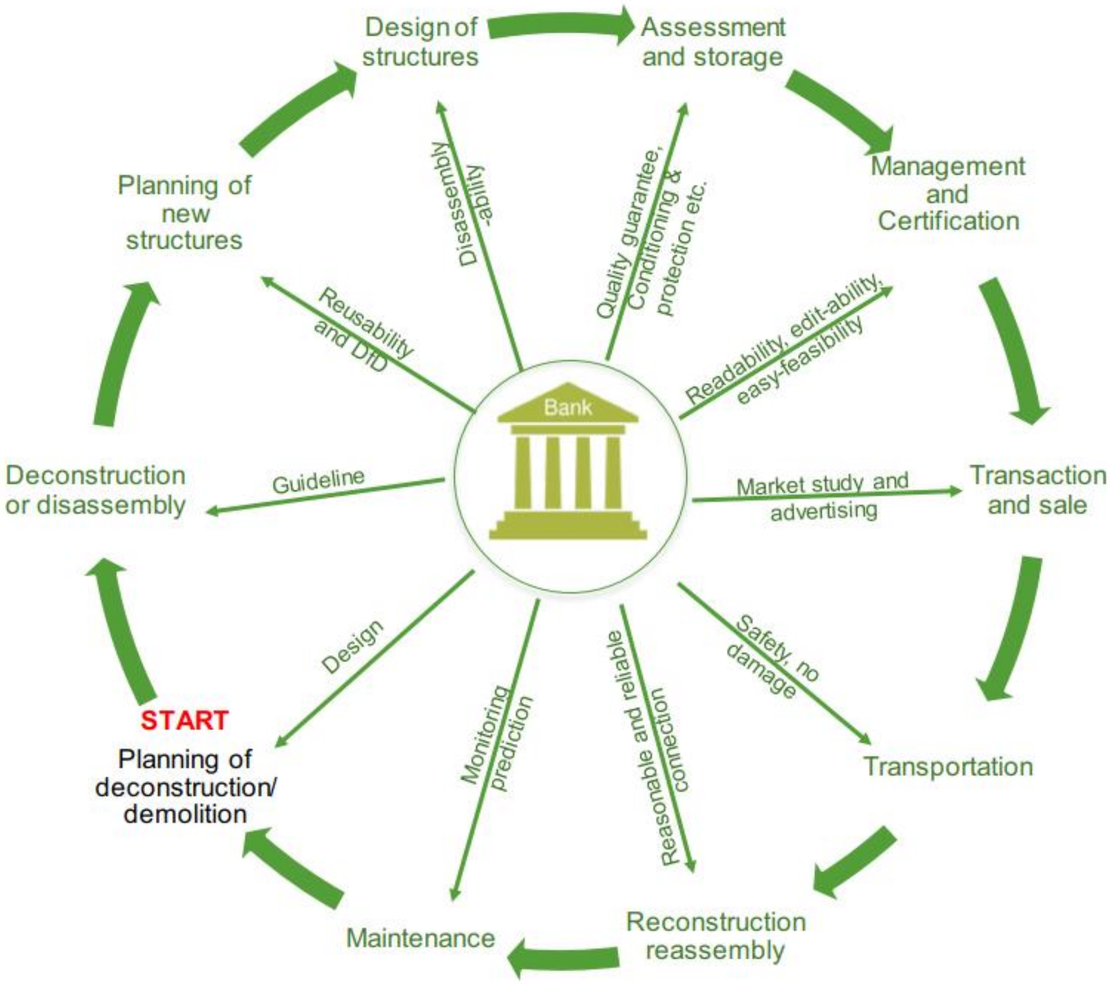

Figure 7: Roles of the material and component bank in the key processes of circular construction (taken from [19])

2.3 - CIRCULAR ECONOMY STRATEGIES IN SUPPLY CHAIN PHASES

Considering the 6 phases of the circular construction supply chain, as depicted in Figure 5, there are circularity practices based on the principles of the 9Rs that can be implemented in each, but at the same time have an impact on the other phases. In this section, a broad and not overly detailed overview will be given, to give an initial orientation on what is meant by best practices of circularity: the following chapter will aim to identify and deepen the most effective and relevant ones.
It is specified from the outset that the practices identified can be implemented both in the construction of new buildings and in the intervention on existing buildings, including those of cultural interest: clearly the application methods are not the same, but must instead be adapted to the context and the possibilities available.

The first phase analysed is the **material supply** one for which, in the perspective of the circular economy, procurement can be realised in two ways: the first concerns the introduction of reused or recycled materials, which therefore reduce the use of virgin raw materials and at the same time limit waste; the second is to be considered only when, in relation to the required performance or other technological needs, it is necessary to use virgin material: in this case, products of natural origin (bio-based) are always to be preferred, which, very often, are able to regenerate themselves [11].

For **manufacturing and delivery**, an application of the circular economy paradigm is implemented by choosing and buying local products, which therefore require less transport and consequently generate fewer emissions; preference must be given to productions in which the use of energy from fossil sources and water, especially drinking water, speaking respectively of embodied energy and embodied water, is limited to the bare minimum, and at the same time there is the integration of renewable sources and the recovery of rainwater. Designers and specifiers should move more towards C2C-certified products, as well as favouring those whose parts or materials can be easily disassembled for reuse or recycling [19]. On the other hand, the responsibility of manufacturers is to ensure the non-toxicity of components, especially if they use recycled parts from other products; to play their part in the circularity of the supply chain, their efforts may include reducing packaging and favouring eco-friendly ones, but above all compliance with environmental regulations and standards. Crucial is also the planning of logistics, which must be geared towards optimising the number of vehicles involved and transports to be carried out [14].

The planning and design phases is undoubtedly central to the transition to a circular built environment: the basic principles to be followed are eco-efficiency and eco-effectiveness, which in themselves encapsulate the concept of C2C and always have as their goal the closed loop, guiding a design focused on ensuring that the building components can be kept in circulation as long as possible and minimising the part of them that becomes waste [14]. The **planning phase** is fundamental in order to define a common circularity objective among the various stakeholders and to guarantee their coordination through the different phases of the building's life cycle; in this preliminary operation it is advisable to identify figures who are experts in the evaluation of environmental impact, but also economic impact, who will subsequently have to deal with guiding the design and operational choices of figures who are not as expert. At the same time, again for authoritative guidance, it is already at this early stage that a competent demolition contractor should be identified to provide a pre-demolition and pre-refurbishment audit of the project site early upfront [20]. The **design stage** is where practical decisions are made for the circularity not only of materials, but also of energy and water. With regard to **materials and components**, in addition to the application of bio-based, low-impact materials derived from recycling and reuse practices, already discussed for the previous phase, the most recurring design concepts and whose relevance is generally recognised [2] are:

- Material-efficient design to facilitate on-site assembly, minimising the number of means and operations to be carried out on site, favouring prefabricated and standardised components;
- Design for adaptability and flexibility, so that the building configuration can be changed over time as required, easily and economically, preferring standardised and modular elements that can be rearranged with each others;
- Design for disassembly and recoverability, to ensure that, at the end of a building's useful life, it can be easily broken down into its components or materials so that they can be introduced into a secondary market for reuse or recycling;
- Design for durability, in which the minimisation of waste production is pursued by adopting materials and configurations that can maintain high performance throughout the life of the building, even after catastrophic events, or that can be restored through constant maintenance facilitated by the design itself.

There is no one approach that is universally better than another, but only in relation to the needs of the client and the intended use of the building: therefore, the end-users and the client must be involved in the design process, to guide the designer in identifying the best design philosophy [19].

With regard to the circularity of **energy**, design solutions oriented towards energy efficiency are much more consolidated and globally applied than those for the circularity of materials; the idea remains that of a building in which heat dispersion is minimised and passive mechanisms are exploited as much as possible: to do this, the airtightness of the building envelope and adequate levels of thermal insulation must be guaranteed, both for opaque and transparent closures, favouring materials with excellent thermal capacity, always paying attention to their environmental impact. In the design of new buildings, it is necessary to carefully study the orientation and configuration of the building in order to minimise thermal loads, while for existing buildings the focus is on how to integrate energy improvement systems with the existing structure and the constraints arising from it, but also on the modernisation of technical implants. Installations, in turn, play an important role in energy efficiency: in the design phase,

dimensioning must be done carefully, taking into account the building's usage scenarios and intended use, always in compliance with current regulations, such as Energy Performance of Building Directive (EPBD), always favouring alternatives in which renewable energy sources are preferred to fossil fuels, such as solar or geothermal energy, even better if produced on-site for self-consumption, and integrating technological solutions for heat recovery [11].
For the circularity of **water**, design choices are limited to the integration of rainwater harvesting cisterns in the building and possible systems to treat it so that it can be reused as drinking water, but these are often expensive and not advantageous in the case of residential buildings; other precautions can be taken by inserting water-saving devices, such as flow regulators, and for keeping drinking water in continuous circulation to avoid the proliferation of bacteria and allow it to be used for longer [11].
It is evident that planners have many alternatives available to integrate circularity into the planning of a building, the problem is to identify which are the best in relation to the purpose of the building or the intervention on it: with a view to maximising circularity and minimising environmental impact, Life cycle assessment (**LCA**) method is undoubtedly the most valid decision-making tool, as it allows one to compare design choices and identify the best from the point of view of, among others, global warming potential (GWP), greenhouse gas emission, or specifically the CO2 emission. Integration with the Life Cycle Cost (LCC) Assessment also makes it possible to analyse the costs, savings and economic benefits of different design options, weighing the choices on the monetary value as well [8]. Another help for planners in navigating the maze of design solutions are the frameworks for achieving Green Building Certifications, such as those of LEED, WELL and BREEAM: adopting designs that meet the guidelines of these certifications automatically leads to sustainable buildings [10].

For the **construction phase**, circularity can be achieved through careful planning of the site and the work schedule and delivery of products to the site. Site design must be careful to limit the negative impact on the natural environment, soil and habitat, not affecting green spaces where not necessary [10]. As already mentioned, it is preferable to produce parts of a building structure off-site to have better control of construction assembly processes and reduced assembly product defects on-site and eliminate wasted efforts of unnecessary assembly tasks and moving of materials, but also reduce the consumption of water and energy [8]. It remains the case that rehabilitation of existing buildings or sites should be preferred to new constructions: in this case, the construction phase becomes the rehabilitation or adaptation phase; before any other on-site operation, hazardous waste remediation and/or solid (toxic or not) waste removal should be accomplished [11].

Use/Operation stage is central with regard to energy efficiency and water efficiency: the central role here is played by the building owners and users, who must be educated and oriented towards a conscious use of the resources, adopting behaviours that aim to minimise water and energy consumption, such as a judicious use of household appliances, or maximising the use of energy produced from renewable sources, instead of the one produced by fossil fuels. In the case of public buildings, however, the wellbeing of the users must never be neglected: adopting systems to control internal thermo-hygrometric conditions that act on the thermal systems allows energy use to be optimised. It is essential that indoor air quality is guaranteed: for this purpose, controlled mechanical ventilation (VMC) is the most advantageous choice, especially if it is equipped with a heat recuperator that allows the circularity of thermal energy [11]. This is also the phase dedicated to the **maintenance** of the building and its systems: adherence to the intervention plan drawn up at the time of design makes it possible to guarantee or even extend their useful life, preventing the need to replace components because they are damaged or malfunctioning [2]. If, on the other hand, an **adaptation** of the building configuration due to a change in space or function requirements is to be made, it is necessary to investigate whether these changes were planned in the design phase and, if so, to operate as indicated in the design.

Otherwise, repurpose is required, but this is part of the **end-of-life** phase of the building supply chain, along with demolition; referring to the change of function of the building, in order to integrate circularity in this phase it is first necessary to screen different transformation and adaptive reuse solutions: design choices are then assumed that take us back, in a circular supply chain, to the planning and design phase. When working on existing built heritage buildings it is rare to encounter examples of design for disassembly or design for adaptability, so waste production is inevitable: what can be done is to create material passports for different components or materials to facilitate their reuse and entry into a second-hand market. In order for materials to be reusable, disassembly or deconstruction should always be preferred over demolition, as it makes it easier to separate materials, identifying which are fully recoverable, which are destined for recycling, and which are destined for waste-to-energy or, in the worst case scenario, landfilling [11]. In this end-of-life phase of the SC, if a company has not already been identified in the planning stage to dismantle the building and, consequently, a plan has not been defined to follow in the procedures and subsequent handling of the materials, it is necessary to coordinate different stakeholders capable of taking care of extracting the materials, transporting them possibly to sorting centers and then identifying collection/deposit centers, as well as, finally making them suitable and available for new use, thus entering the SC of a new building [2].

CAP. 3 - BEST PRACTICES OF CIRCULARITY FOR THE CROSS-BORDER COSTRUCTION SECTOR

While the previous chapter specified the circular management strategies of the entire supply chain and how to integrate specific techniques for the stages of the supply chain, in this chapter we would like to delve into the best circularity practices applicable in the building lifecycle, without tying them to one step of the supply chain, but collecting all the ways in which they can bring benefits to construction. A global literature scouting was therefore carried out to identify these generalised practices and consequently what was considered relevant and helpful to approach and educate stakeholders was collected in summary sheets. These 15 documents are available as an appendix to the report.

3.1 - LITERATURE REVIEW

The literature review was carried out with the aim of identifying with which building design and management practices circularity can be improved and ensured in the sector, not only limited to those related to the circularity of materials, but also of resources such as water and energy: to do this, a series of keywords were identified that were considered significant for the purpose of the research, i.e. 'best practices', 'construction', 'circular economy', 'building', 'circular practices', making strings with these with the help of the 'AND' and 'OR' operators, such as ' "best practices" AND "building" AND "circular economy" '.
The databases used for the bibliographic search were Science Direct and Scopus: the same keyword combinations, or adaptations thereof, were used to locate articles, conference proceedings and book chapters (henceforth, all documents will be referred to simply as 'papers') on both platforms. More advanced search methods were not used in order to obtain as complete a picture as possible of the studies currently available on the subject.
By July 2024, the time of the first search, the total number of articles fulfilling the above-mentioned criteria was over 1200; an initial selection of relevant articles was made on the basis of their title and abstract: this reduced the selection to a more reasonable number of 140 papers. The bibliographical references of the latter were exported to a reference manager software, Zotero, which made it possible to eliminate the duplicate articles resulting from the union of the results of the two databases: the final number of articles to be read was therefore 133.

From a thorough reading of them, it was possible, first of all, to remove 14 other items from the bibliography because they were not exclusively related to the construction sector or because they focused too much on sustainability instead of circularity or on individual building products. Figure 7 shows the path followed for the selection of articles in the literature review.

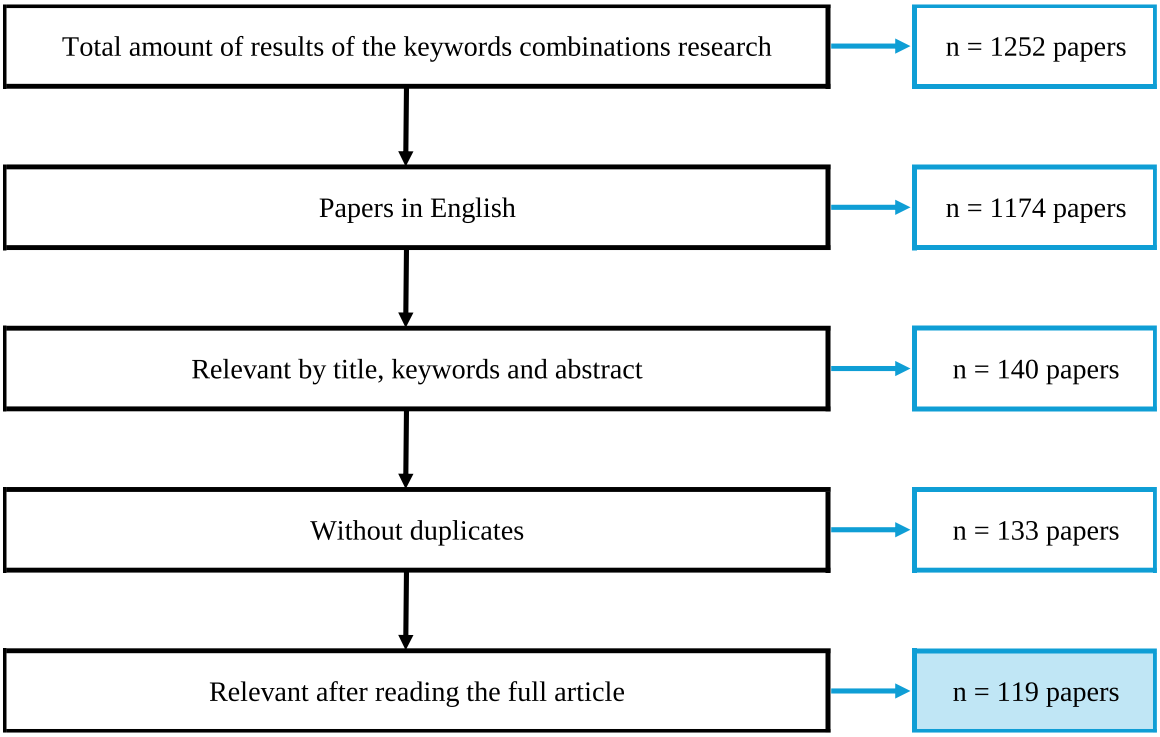

Figure 8: Path followed in the best practices literature review

On the final bibliography, a study was also made with respect to the time trend of the number of papers published for each year (Figure 9) and the country indicated for the first author of each paper (Figure 10).

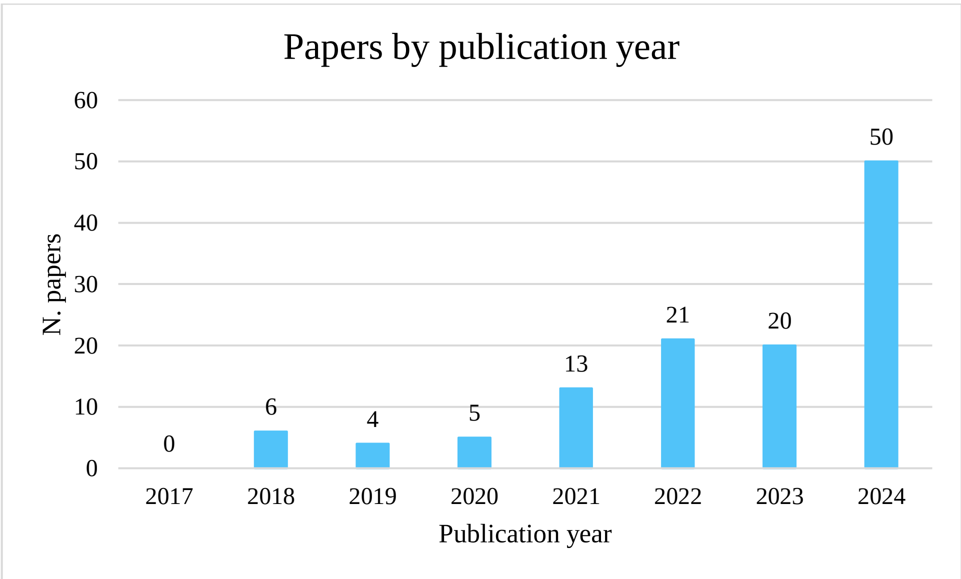

Figure 9: Papers about best practices by publication year

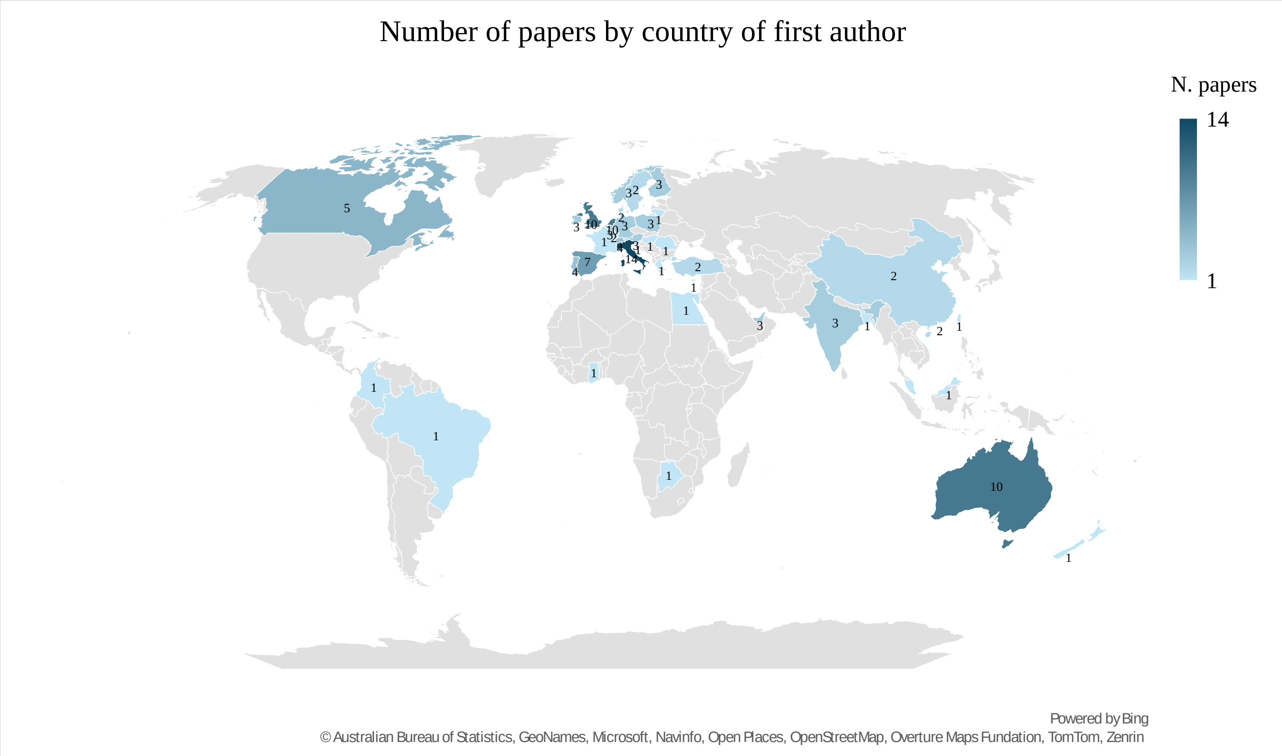

Figure 10: Geographical distribution of papers by country of first author

With regard to the distribution over the years of the number of papers considered relevant on the subject, the same observations already made for the literature review in Chapter 2 apply: in fact, the growth of publications in the last year was exponential compared to previous years. From the point of view of the geographic origin of the first author, Europe shows a clearly greater commitment to research on the topic, with a total of 85 articles out of the 119 total read. Furthermore, Italy appears to be the first country in terms of number of publications, at 14, followed by Australia, the Netherlands and the United Kingdom, all three with 10 publications; Slovenia, on the other hand, has only one article to its credit per first author origin.

The reading of the papers was therefore geared towards identifying the practices based on the principles of the circular economy that are most recognised for the transition of the construction sector, with regard to the circularity of materials, energy and water, at all stages of the construction supply chain. In order to have an initial overview as complete as possible, the first texts among those collected to be read were the literature reviews (e.g. [7], [21], [22], [23], [24], [25]): during their reading, the most recurring topics or, even, best practices that were identified and catalogued in the articles themselves were kept track of. We then proceeded to read through all the articles, gradually outlining what the best practices might be until 15 were identified.

3.2 – BEST PRACTICES

Circularity best practices are identified and outlined in such a way as to be representative and encompass all building design and management techniques; in particular, there was a desire to limit the number of them by encompassing different approaches and/or approaches that had the same end goal or basic circularity philosophy in the same strategy.
A brief description of the best practices is provided here, each with a capital letter to identify them, while for a more in-depth discussion of each one, please refer to the data collection sheets in the appendix.

- A – MATERIAL-EFFICIENT DESIGN
  This practice involves designing the building or intervening on it to minimise the production of construction and demolition waste (C&DW), a technique also known as Designing-out waste; this practice includes all the precautions that serve to limit not only material waste, but also the use of energy and water during the construction phases: these include the use of prefabricated or off-site components, careful planning of the construction site and its phases.

- B – MATERIAL CIRCULARITY
  This includes all the actions and choices that can be made in order to ensure a technical material cycle that is as closed as possible: this means minimising the use of virgin materials, favouring the reuse of building components or materials from recycling procedures. At the same time, this practice also involves planning, if closed-loop is not possible, the end-of-life treatment of C&DW.

- C – USE OF BIO-BASED MATERIALS
  Whereas best practice B was intended to close the technical cycle, this one aims to go through the biological cycle: it envisages using natural, bio-based and self-generating materials, whose use is not harmful to the environment, but rather can become nourishment at their end of life, without generating any waste.

- D – USE OF LOW-IMPACT MATERIALS
  This practice makes it possible to reduce the environmental impact of construction by choosing low-impact materials, both from the point of view of the emission of toxic particles during the life of the components, but above all in the production phases: this means materials with a low carbon footprint, as well as reduced embodied energy and water; in compliance with this practice there is a preference for local materials and decarbonisation materials.

- E – DESIGN FOR DISASSEMBLY / DEMOLITION / DECONSTRUCTION
  In this case, it is a building design strategy to make choices at an early stage to ensure its disassembly, deconstruction or demolition at the end of its useful life; in this way, the building can be decomposed into its parts, allowing the recovery of components and/or recycling of materials can be maximised, avoiding the production of C&DW.

- F – DESIGN FOR ADAPTABILITY / FLEXIBILITY
  It is always a circular design strategy to extend the useful life of a building as much as possible, ensuring simple and inexpensive configuration changes to adapt to changes in space or user function requirements. Designs based on modular elements are also part of this practice, as these are also designed to be rearranged according to needs.

- G – DESIGN FOR DURABILITY / RESILIENCE / MAINTAINABILITY
  This design strategy is also based on ensuring the longest possible service life of the building, however not allowing changes in its course, but maximising the quality and accuracy of the design so that the building is able to maintain its optimal performance, even in the event of catastrophic events. It envisages the use of high-performance materials, advanced design techniques for seismic and fire resistance, and layouts that allow for unobstructed maintenance.

- H – IMPLEMENTATION OF DIGITAL TECHNOLOGIES
  This practice encompasses all the digital technologies that can be implemented to improve the design and management of the building in all its life stages. This includes, for example, the use of BIM for the integration of different design aspects, 3D printing for the production of components, sensor technology for building monitoring, and home automation for the optimised regulation of conditions inside the building.

- I – CREATION OF OR PARTECIPATION TO COLLABORATIVE PLATFORMS / DATABASES
  This strategy encompasses all solutions that can be used to ensure interaction between different stakeholders from the same project, the same sector or even different sectors, so as to favour co-design, co-production and the circularity of reuse and recycling materials. These include online databases to catalogue and sell materials, websites or applications for sharing projects and ideas concerning the introduction of the circular economy in the construction sector.

- J – DRAFTING AND USE OF MATERIAL PASSPORTS AND CERTIFICATIONS
  This practice allows for a conscious and careful choice of materials: as far as environmental certifications (e.g. Environmental Product Declarations) are concerned, they allow the manufacturer to demonstrate a commitment to minimising environmental impact and contractors to choose the best materials not only according to mechanical performance. Material passports are more useful as guarantees for reuse, as they can gather information on provenance, operations performed on the materials and performance.

- K – LIFE CYCLE AND LIFE CYCLE COSTING ASSESSMENT
  LCA and LCC are extremely valuable tools for comparing project choices: LCA in particular allows the identification of the best interventions from an environmental point of view, while LCC can be used as support for an evaluation of the project cost, but also for the quantification of gains and benefits deriving from the adoption of circular choices in the design and management of the building. LCA in turn is useful for calculating the environmental performance of individual products and for demonstrating the validity of the choice.

- L – DESIGN FOR ENERGY EFFICIENCY
  This strategy in the design of new buildings or intervention on existing buildings makes it possible to minimise energy waste by reducing heat loss, maximising the use of free inputs and ensuring efficient operation of air-conditioning systems. It also includes the introduction of systems for monitoring indoor conditions and passive mechanisms.

- M – TRANSITION TO RENEWABLE ENERGY SOURCES
  For the circularity of energy to be realised, it is desirable that renewable sources take the place of fossil fuels: with this in mind, the introduction of on-site production systems to meet the needs of buildings is relevant, but also choosing building materials that are produced using solar, wind or geothermal energy.

- N – WATER SAVING AND MANAGEMENT
  This practice includes all the solutions that can be adopted in the production, design, construction and use phases of the building for water saving and water circularity; we speak both of introducing rainwater harvesting and treatment systems in buildings, and of choosing products with reduced embodied water. At the same time, this also includes the attention that must be paid in the design towards hydraulic invariance.

- O – RELIANCE ON BUILDING CERTIFICATIONS AND CIRCULARITY INDICATORS
  Building certifications and circularity indicators can be useful to demonstrate that design choices meet impact objectives, not only environmental. Designing to achieve certifications also provides a framework in which to orientate decisions. Relying on these measurements is the only way to quantify the circularity of water and energy.

Having arrived at the definition of these 15 practices, a re-reading of the articles made it possible to identify, for each one, the number of texts explicitly pointing to it or to behaviours that are indispensable for it: in this way it was possible to have an idea of the relevance of the various best practices identified within the scientific literature on the subject; the results are collected in Table 1.

Table 1: Best practices citations and relevant papers

ID	BEST PRACTICE (BP)	N. CITATIONS	PAPERS RELAVANT FOR THE PRACTICE UNDERSTANDING
A	MATERIAL-EFFICIENT DESIGN	65	[7]; [26]; [27]; [28]; [29]
B	MATERIAL CIRCULARITY	96	[2]; [30]; [31]; [32]; [33]; [34]; [35]; [36]; [37]
C	USE OF BIO-BASED MATERIALS	21	[38]; [39]; [40]; [41]
D	USE OF LOW-IMPACT MATERIALS	40	[42]; [43]; [44]; [45]; [46]
E	DESIGN FOR DISASSEMBLY	79	[47]; [48]; [49]; [50]; [51]; [52]; [53]
F	DESIGN FOR ADAPTABILITY	56	[39]; [54]; [55]
G	DESIGN FOR DURABILITY	28	[56]; [57]
H	IMPLEMENTATION OF DIGITAL TECHNOLOGIES	66	[58]; [59]; [60]; [61]; [62]; [63]; [64]
I	PARTECIPATION TO COLLABORATIVE PLATFORMS AND DATABASES	50	[40]; [65]; [66]; [67]
J	DRAFTING AND USE OF MATERIAL PASSPORTS AND CERTIFICATIONS	61	[68]; [69]; [70]
K	LCA / LCC	81	[71]; [72]; [73]; [74]; [75]; [41]; [76]; [77]
L	DESIGN FOR ENERGY EFFICIENCY	42	[78]; [79]; [80]; [81]
M	TRANSITION TO RENEWABLE ENERGY SOURCES	27	[54]; [56]; [82]; [83]
N	WATER SAVING AND MANAGEMENT	11	[84]; [85]
O	RELIANCE ON BUILDING CERTIFICATIONS AND CIRCULARITY INDICATORS	40	[72]; [86]; [43]; [87]; [88]; [89]; [90]

For the completion of the summary sheets, information from the various papers in the table was used: as no paper was limited to a specific best practice, the complex work was to extrapolate from each one what was of interest; the main information for the compilation was, for each best practice, that contained in the papers in the respective row, however, if one wished to go deeper, it is advisable to also read the other papers in the bibliography to get a complete picture.

CAP. 4 - CROSS-BORDER BUILDING STOCK

The literature review on the future possibilities of a circular construction sector had to be complemented by an analysis of the current situation of the cross-border built heritage, in order to understand how circularity can be introduced through interventions on the existing building stock or through circular management of their supply chain.

4.1 - STATISTICAL DATA FOR BUILDING STOCKS

To obtain information on the buildings in Italy and Slovenia, reference was initially made to the data made available from the latest building censuses, carried out for the two states respectively by Istat [91] and SiStat [92]; the results obtained for each state will then be examined in detail and a comparison between the two will be presented.

4.1.1 – Italy

At the 2011 census, the last complete one carried out by ISTAT for the built heritage, there were a total of about 14.5 million buildings in Italy, of which 84% are regularly used (about 13.7 million buildings); the distinction between uses is shown in Figure 11, with a clear predominance of residential buildings, about 12.2 million in total. Most of the data collected from building censuses refer only to residential buildings, so we will focus on these, since they are also, as we have seen, the predominant part; to have an estimate in the regions of interest for the cross-border context, in Veneto this category counts just over one million buildings, three times as many as in Friuli-Venezia Giulia (about 300 thousand).

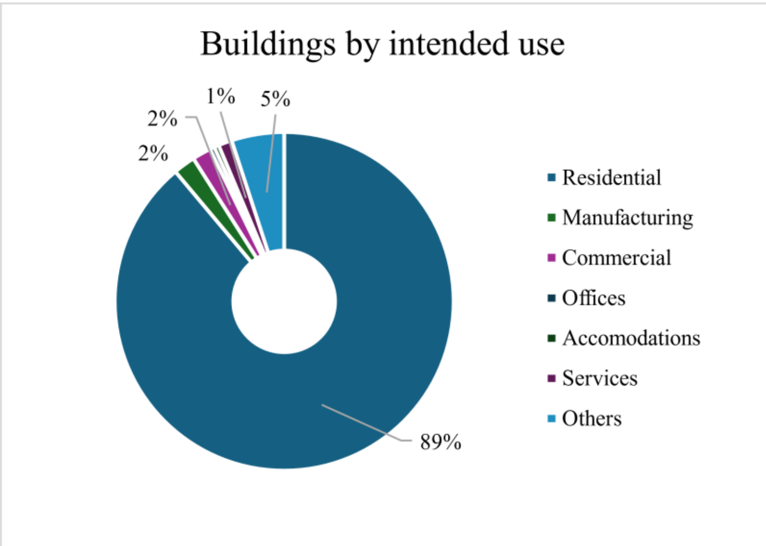

Figure 11: Italian buildings distrubution in 2011 by intended use

The most recent Istat census giving some information on buildings dates back to 2021, in which the number of residential buildings compared to 2011 increased by approximately 230000. The graph depicts the number of new residential buildings constructed for each decade or year interval shown in Figure 12: it can easily be seen that more than 50 per cent of the existing residential buildings were built before 1970, when no building energy efficiency legislation was in force. Equally evident is the decrease in new constructions from 1980 to the present, with a drastic collapse in the decade 2011-2021: given the small number of buildings constructed in these 10 years and the lack of more specific recent data, for a more in-depth analysis of the Italian built heritage and the regions of interest we have used data from the 2011 Istat census.

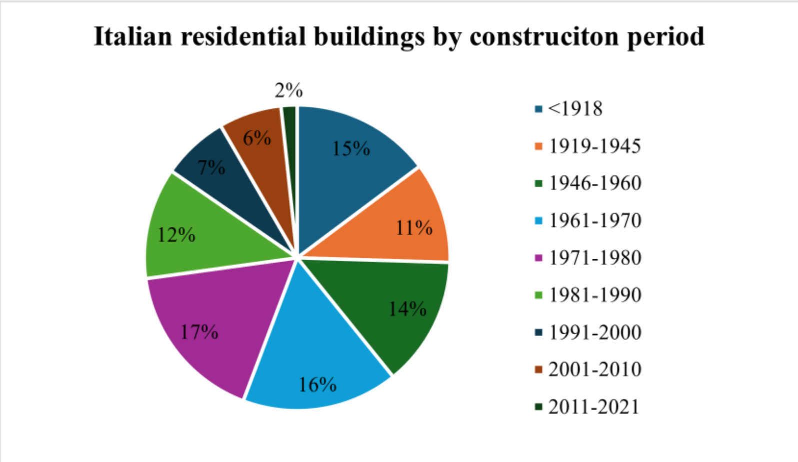

Figure 12: Italian residential buildings by construction period

From the 2011 census it was also possible to obtain a general indication of the construction technique used; in particular, a classification was made on the material mainly used for the structure of residential buildings, with a distinction between buildings in load-bearing masonry, reinforced concrete and the other materials: Figure 13 shows a progressive abandonment of load-bearing masonry in favour of the use of reinforced concrete, already the material of choice for construction since the 1970s. As for buildings made of the other materials, which include steel and wood, they are always fewer in number than those made of concrete and masonry, while they are much more used in non-residential buildings with large spans.

Having available region-specific data, we focused on Veneto and Friuli-Venezia Giulia, which are of interest in this study about cross-border situation: by comparing the two relative graphs in Figure 14, it can be seen that in Veneto the use of masonry in proportion to other materials has always been greater than in FVG; at the same time, the great growth in the use of reinforced concrete in FVG can be seen starting in the 1970s, coinciding with the reconstruction following the earthquake in Friuli in 1976 and the consequent development of new, more modern, seismic-resistant building techniques.

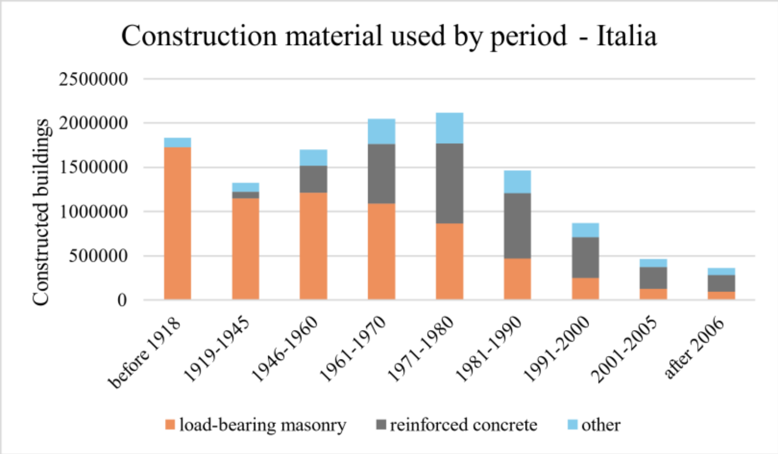

Figure 13: Distribution of Italian residential buildings by material used for the bearing structure and by period of construction

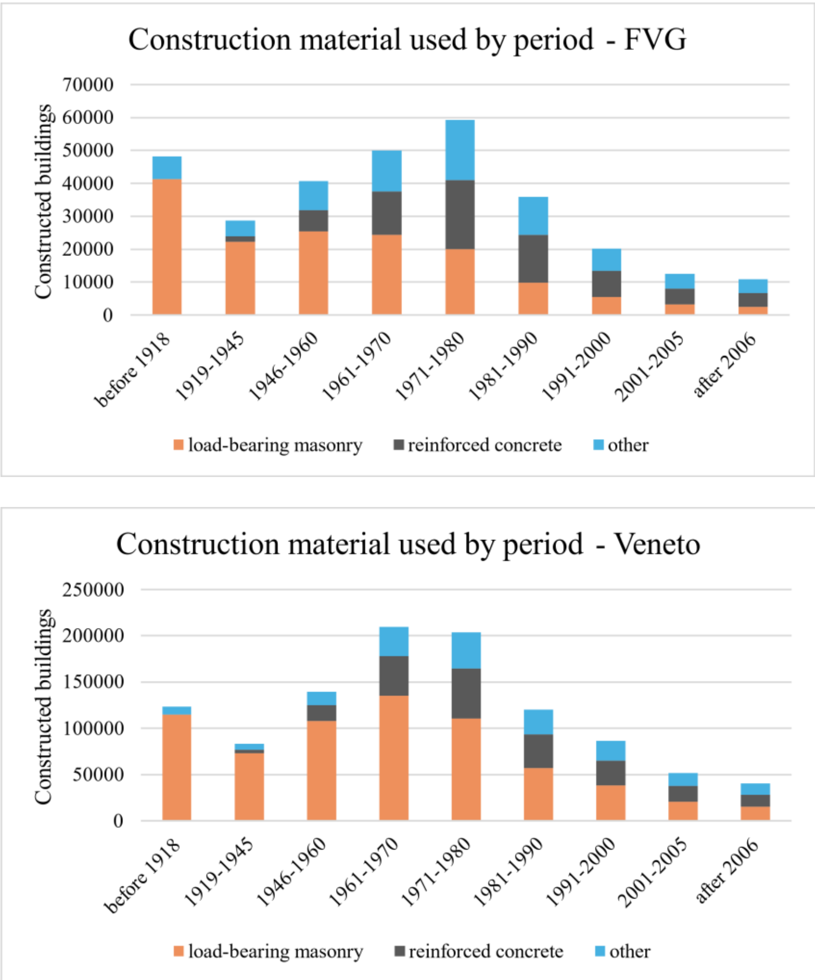

Figure 14: Comparison between FVG and Veneto buildings by material used for the bearing structure and by period of construction

Istat, however, does not give an indication of the proportion of building types in the Italian heritage, i.e. the number of detached or terraced dwellings as opposed to multi-apartment buildings: a rough quantification can be obtained by observing the subdivision of buildings by number of dwellings; the percentage corresponding to the single dwelling is to be considered as an example of single-family residential buildings: Figure 15 show that in Italy, as well as in Veneto and FVG, this type accounts for more than half of the built heritage, while just under a quarter of the buildings are two-family ones.

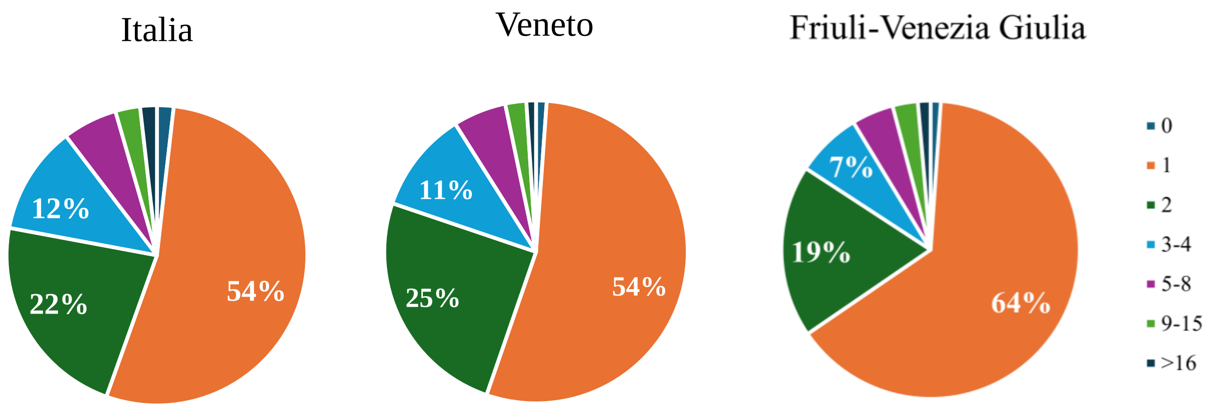

Figure 15: Comparison of building percentages by number of dwellings in Italy, Veneto and FVG

4.1.2 – Slovenia

As far as the Slovenian situation is concerned, the last census of buildings carried out by SiStat in which there was cataloguing according to the material of the load-bearing structure and the age of construction dates back to 2002, with a subsequent adjustment in 2007, which can somewhat provide an indication of the built heritage. Since for Italy we have limited ourselves to residential buildings, although data is also available for other building types, the same will be done for Slovenia. As we can see in Figure 16, as seen for Italy, also for Slovenia the peak of construction occurred between 1970 and 1980, while in a different way there has been a considerable use of new residential buildings since the 2000s, with the construction of an average of 3000 buildings per year.

In Figure 17, a comparison is then made with respect to the materials used for the load-bearing structure of residential buildings, using the classification used in the 2011 Italian census: in the Slovenian case, concrete and reinforced concrete buildings have been distinguished in the cataloguing, enclosed for ease of comparison within the Italian category corresponding to reinforced concrete, stone and brick buildings have been included in the masonry category, and finally, in the "other" section, both the buildings specified to be made of wood and those for which no further details are given have been counted. In addition to the comparison between Veneto and FVG, it may be noted that three quarters of the Slovenian built heritage consists of masonry buildings, with concrete used for the load-bearing structure in only 6% of the total buildings.

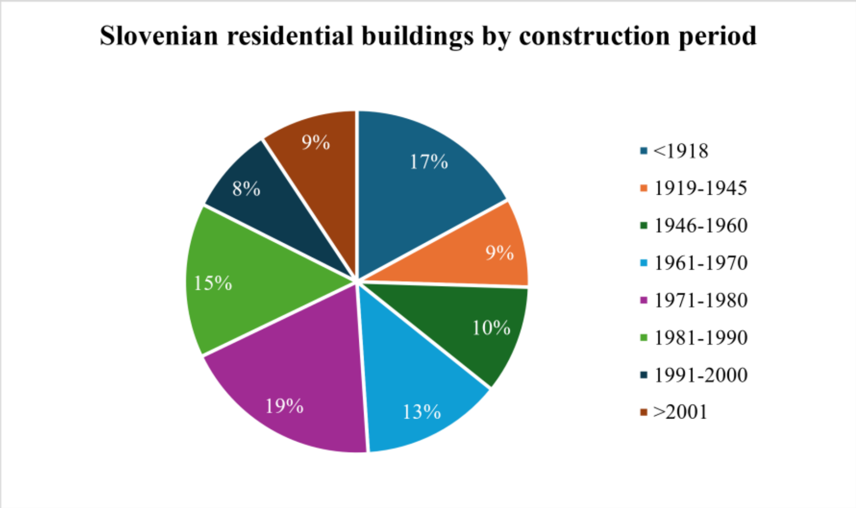

Figure 16: Slovenian residential buildings by construction period

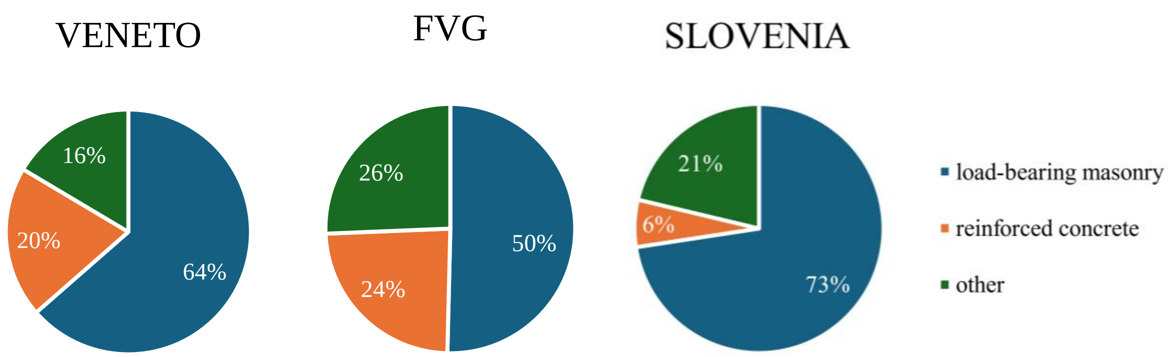

Figure 17: Comparison of material used for the bearing structure between Veneto, FVG and Slovenia

The latter data can be translated into the presence of few multi-storey buildings, concentrated in large cities, which are at the same time the few residential buildings that are built in reinforced concrete. In support of this, Figure 18 shows Slovenian residential building statistics by type, distinguishing isolated houses, contiguous or terraced houses and apartment blocks.

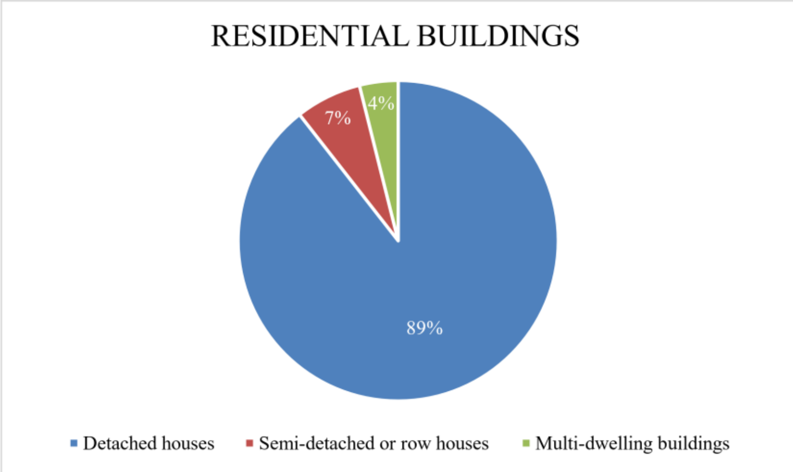

Figure 18: Distribution of building typologies in Slovenia

4.2 – ITALIAN AND SLOVENIAN BUILDING TYPOLOGIES COMPARISON

From the Eurostat portal [93], the Statistical Office of the European Union, it was possible to make graphs comparing for the EU, Slovenia and Italy, the distribution of the population between rural areas, villages/suburban areas and cities and, for each of these categories, a further subdivision on the basis of the type of building of residence, between detached houses, terraced houses, buildings with up to 10 flats and with more than 10 flats; Figure 19 is representative of how in Italy there are many more multi-apartment buildings, with a large concentration of the population in the cities, while in Slovenia the trend is diametrically opposed, with a higher population density in rural areas and a preponderance of detached houses, in which more than the 65% of the population lives.

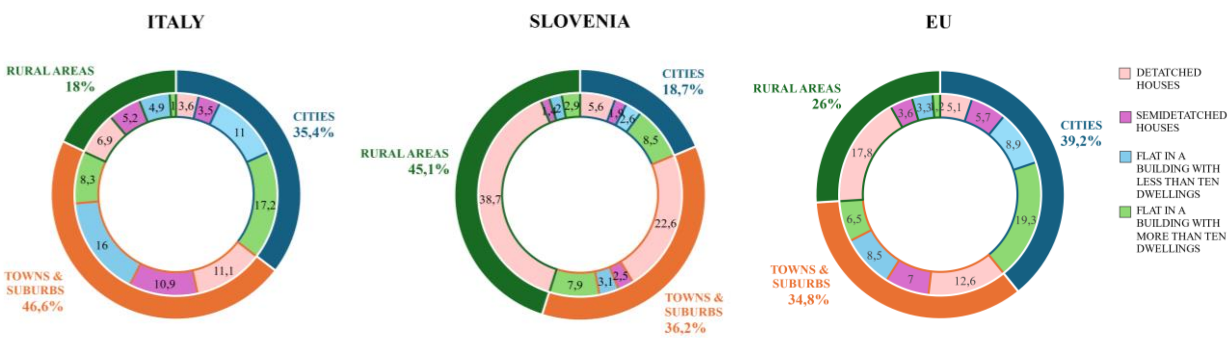

Figure 19: Comparison between Italian, Slovenian and EU distribution of population and buildings

This preliminary analysis has made it possible to observe statistically which buildings are more or less present in the area of interest, however, it provides too little information on the construction details of the buildings, which make it possible to really understand what interventions can or cannot be made on them in the perspective of circularity: for this purpose, we made use of the descriptive sheets of the building types elaborated for the two states, Italy [94] and Slovenia [95] within the TABULA project (Typology Approach for BUiLding stock energy Assessment), within the European programme Intelligent Energy Europe. This project achieved a harmonisation in the classification of European residential building types, based on energy characteristics, in order to define for each one of the standard or advanced upgrading measures possible to increase energy savings and adhere to the requirements of the Energy Performance of Buildings Directive (EPBD, 2002/91/EC): although our focus is different, the results obtained from this project are very useful for us to get an overview of the buildings and their qualities. It is specified that the typologies identified for Italy are those identified for climate zone E, the largest in Italy, and representing a large part of the territory of Veneto and Friuli-Venezia Giulia, i.e. the one we are interested in.

The direct comparison of the building types of Italy and Slovenia provided in the programme was complex due to the different time intervals at which they were studied in the two states: in the case of Italian buildings, they were classified into 8 different construction periods, starting with buildings prior to 1900, whereas in the case of Slovenian buildings, there are only 5 time categories. A series of observations made it possible to group the different time intervals into 4 large periods, as shown in Figure 20:

- the first affects all buildings constructed before 1945, thus the most historical part of the buildings;

- the second is the one that includes buildings mainly resulting from post-World War II reconstruction, but in the absence of special regulations on energy efficiency;

- period 3 encompasses buildings constructed at the end of the last century, but made with a special focus on energy performance, following the energy crisis of 1973 and the subsequent national regulations aimed at reducing energy consumption in 1976 and 1987 in Italy and Yugoslavia respectively;

- the last period includes more recent, 21st century buildings, whose energy aspects are increasingly relevant and regulated by European Union regulations (of which Slovenia has been a member since 2004).

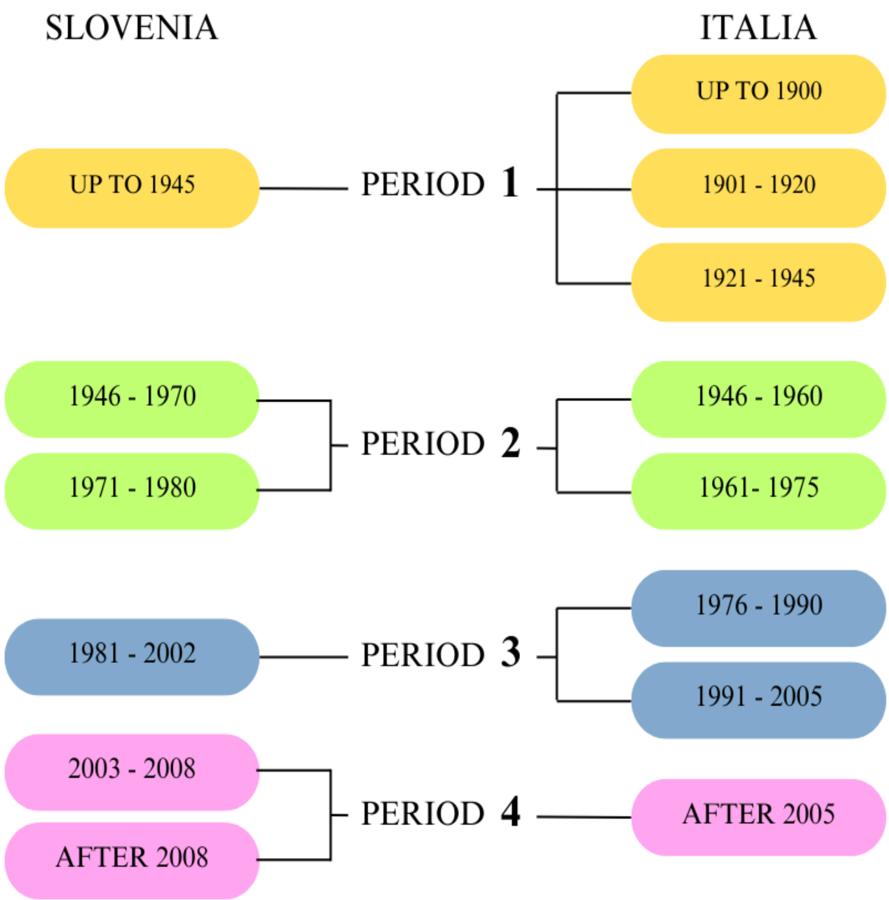

Figure 20: Definition of comparison periods

For each period, the analysis focuses on the four main categories of residential building, i.e. single-family house (SFH), terraced house (TH), multi-family house (MFH) and apartment block (AB); despite this specialisation on dwellings, the construction techniques of each period are considered to be validly represented for all categories of use, always depending on the size of the building. For each category, the construction techniques of floors, walls and roofs, the type of window and door frames and the heating (Heating System - HS) and domestic hot water production (Domestic Hot Water - DHW- System) systems are provided: as it was the aim of the programme to identify the possibilities of improving the energy efficiency of the built heritage, for each period of construction and type, upgrading interventions are suggested for both the building envelope and the system. The objective of the identified interventions is not explicitly circularity, however these are reported with the reminder that design for energy efficiency is one of the strategies for integrating EC into the building supply chain highlighted in the first phase of analysis.

4.2.1 – Period 1

From the observations in the TABULA documents, it can be seen that SFHs and THs, and similarly MFHs and ABs, have similar construction methods, so the comparison between Italy and Slovenia will be made in general on single-family and multi-family buildings.
The Slovenian single-family house, and similarly terraced house, has a wooden roof (with rafters and floorboard) on which the tile covering rests; the other floors consist of a high concrete casting on which wooden rafters and consequently the floorboard rest. As for the envelope, the load-bearing walls are made of natural stone, while the window and doorframes typically have a wooden frame and single glass; there is usually the use of double glazing to create a thermal buffer.

In spite of minor differences, the three typologies identified for the same types of residential buildings in Italy, representative of buildings constructed before 1945, present in general many similarities with Slovenian constructions of the same period: first of all, the roof slab is made identically of wood, as are the frames of the window and door frames (although metal was initially preferred), always characterised by single-glazing. The load-bearing structure is masonry, only that, unlike in the Slovenian context, layers of solid bricks are added to the natural stone to improve regularity, until the entire building is made of brick. The load-bearing component of the floors is a solid slab of unreinforced concrete, on which the floor finishes are superimposed.

As far as multi-occupancy buildings are concerned, in common with the other typologies is the use of single-glazed window frames with wooden frames, always used with the double-window configuration in Slovenia, except for an introduction of double-glazed windows in the ABs. Similarities can also be seen in the supporting structure, generally made of solid brick (initially stone), with some avant-garde use of hollow bricks and concrete for multi-storey buildings.
Also in this geographical context, there is the use of the previously described roof slab with wooden beams, which is however supplemented with a concrete slab compared to the solution for single-family buildings; the same is done for the intermediate floors, while the slab at the base of the building only includes the concrete slab on the ground.

In Italy, on the other hand, wooden floors in multi-family buildings were rare, while the most widespread types of construction before 1945 were characterised by vaulted brick horizons and their evolution with supporting steel beams, also used in flat brick floors; the end of the first period also saw the introduction of the first examples of ribbed reinforced concrete floors.

Figure 21 summarises the relevant information derived from this analysis.

COUNTRY	TYPOLOGY	WINDOWS		EXTERNAL WALLS MATERIAL	INSULATION PRESENCE	HEATING SYSTEM	DHW SYSTEM
		FRAME	GLASS				
SLO	SFH	Wood	Single	Natural stone	☐ ext. walls ☐ floors ☐ roof	Wood-fired furnace, in unheated space	Electric boiler in heated space
	TH	Wood	Single	Natural stone	☐ ext. walls ☐ floors ☐ roof	Wood-fired furnace, in unheated space	Electric boiler in heated space
	MFH	Wood	Single	Solid bricks	☐ ext. walls ☐ floors ☐ roof	Centralized, with traditional gas boiler in unheated space	Autonomous, Electric boiler in heated space
	AB	Wood	Single	Concrete	☐ ext. walls ☐ floors ☐ roof	Centralized, with traditional gas boiler in unheated space	Autonomous, Electric boiler in heated space
ITA	SFH	Metal or Wood	Single	Natural stone and/or solid bricks	☐ ext. walls ☐ floors ☐ roof	Traditional gas boiler in heated space, uninsulated pipes	Electric or instantaneous boiler, without recirculation
	TH	Wood	Single	Natural stone and/or solid bricks	☐ ext. walls ☐ floors ☐ roof	Traditional gas boiler in heated space, uninsulated pipes	Electric or instantaneous boiler, without recirculation
	MFH	Wood	Single	Natural stone and/or solid bricks	☐ ext. walls ☐ floors ☐ roof	Centralized, with traditional gas boiler in unheated space, uninsulated pipes	Autonomous, Electric or instantaneous boiler, without recirculation
	AB	Metal or Wood	Single	Solid bricks	☐ ext. walls ☐ floors ☐ roof	Centralized, with traditional gas boiler in unheated space, uninsulated pipes	Centralized, with gas boiler, with recirculation

Figure 21: Summary table for period 1 buildings

Interventions that can be identified to improve energy efficiency are presented here, broken down by building component:

- ENVELOPE
  - Replacement of windows and doors with double/triple chamber with noble gas filled gap, wooden frame, low-emissive glazing
  - Application of insulation material in roofing, floors and external walls, in a thickness sufficient or greater than that required to reach the transmittance (U) limit for the regulation or to achieve a given certification
- HEATING SYSTEM
  - insulation of distribution network
  - removal of old boiler
  - installation of a new generator in heated room chosen between condensing boiler, air-water or geothermal heat pump, wood biomass boiler
  - installation of solar thermal panels for water pre-heating
  - installation of photovoltaic panels for electricity production, especially in the case of presence of heat pumps
  - replacement of radiator systems with radiant panel systems
  - in multi-family buildings preference should be given to centralising the heating system

- DHW SYSTEM
  - introduction of pumps for recirculation
  - insulation of distribution piping
  - installation of solar thermal panels, with adequately insulated storage tanks in heated rooms
  - in multi-family buildings preference should be given to centralising the DHW production system, with the possible introduction of autonomous electric boilers
  - installation of a new generator in heated rooms, chosen between condensing boiler or air-water or geothermal heat pump, or use of the newly introduced generator for the heating system
- Introduction of Mechanical Controlled Ventilation (VMC) systems with heat exchanger

4.2.2 – Period 2

In analogy with the first period of analysis, a comparison can be made by grouping the first two and last two categories of buildings for each state.

Starting from the Italian SFHs and THs built between 1946 and 1975, no particular evolution is noted with respect to pre-1945 buildings, especially in the stratigraphy: only starting with law no. 373 of 1976 "Regulations for the containment of energy consumption for thermal uses in buildings" and its prescriptions for the thermal insulation of buildings have there been real changes, while in the second period under consideration building was much less schematic and rigorous, aiming at reconstruction as quickly as possible, also taking advantage of the economic boom without attention to the use of resources.

One of the main differences that can be observed in comparison with the buildings of the first period is the progressive abandonment of wood in favour of concrete, however with a certain shrewdness in the need to reduce the weight of the structures: this is translated into roofing slabs lightened by the introduction of hollow flooring blocks and the realisation of the walls with hollow bricks, with a minimum increase in their thickness, sometimes with a cavity between the two layers to provide some insulation; however, neither in the slabs nor in the walls is the use of real insulating materials developed. As far as windows and doors are concerned, most of these buildings still have single-glazed windows and doors with wooden frames.

The Slovenian counterpart of the same type of buildings from the same period, despite the fact that there was no specific legislation on energy saving at the time, is more developed in terms of reducing dispersion: the focus on building insulation led to the introduction of a layer of insulating material in the typical wooden beam roof and concrete floors, as well as in the hollow brick walls, but above all to a change from single to double glazing, while still maintaining the wooden frame. Compared to Italian buildings of the same era, one notices the lack of the use of lighteners in the floors, with lower total thicknesses of the building packages.

The same observations also apply to MFH and AB: in Italy the floors are typically made of lightweight concrete with hollow blocks, the walls with hollow bricks, sometimes with an air gap, and the windows and doors of single-glazed timber. In Slovenia, the most common floor is still that of wooden joists resting on a reinforced concrete slab, not always with an insulating layer in between; the walls in the case of MFH are made of concrete blocks, while in the case of AB of cast concrete, in both cases without the addition of insulating layers. The windows and doors remain double-glazed with wooden frames, as in the other two building types.

Figure 22 summarises the relevant information derived from this analysis.

COUNTRY	TYPOLOGY	WINDOWS		EXTERNAL WALLS MATERIAL	INSULATION PRESENCE	HEATING SYSTEM	DHW SYSTEM
		FRAME	GLASS				
SLO	SFH	Wood	Double	Hollow bricks	☐ ext. walls ☐ floors ☒ roof	Traditional gas boiler in unheated space	Gas boiler in heated space/combined with HS
	TH	Wood	Single	Hollow bricks	☐ ext. walls ☒ floors ☒ roof	Traditional gas boiler in unheated space	Gas boiler in heated space/combined with HS
	MFH	Wood	Double	Concrete blocks	☐ ext. walls ☒ floors ☐ roof	Centralized, with traditional gas boiler in unheated space	Autonomous, Electric boiler in heated space
	AB	Wood	Double	Concrete	☐ ext. walls ☒ floors ☐ roof	Centralized, with traditional gas boiler in unheated space	Autonomous, Electric boiler in heated space
ITA	SFH	Wood	Single	Hollow bricks	☐ ext. walls ☐ floors ☐ roof	Traditional gas/oil boiler in heated space, uninsulated pipes	Combined with HS, with recirculation
	TH	Wood	Single	Hollow bricks	☐ ext. walls ☐ floors ☐ roof	Traditional gas boiler in heated space, uninsulated pipes	Combined with HS, with recirculation
	MFH	Wood	Single	Hollow bricks	☐ ext. walls ☐ floors ☐ roof	Autonomous, with traditional gas boiler in unheated space, uninsulated pipes	Autonomous, electric boiler/combined with HS, without recirculation
	AB	Wood	Single	Hollow bricks with cavity or concrete	☐ ext. walls ☐ floors ☐ roof	Centralized, with traditional gas boiler in unheated space, uninsulated pipes	Centralized, with gas boiler, with recirculation

Figure 22: Summary table for period 2 buildings

Interventions that can be identified to improve energy efficiency are the same presented fot period 1 buildings.

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4.2.3 – Period 3

This third period is characterised by a design and construction that is more sensitive to energy performance and the well-being of the inhabitant, following the issuing of the standards already mentioned.

In Italy, in particular, the change was radical, with the introduction in all structural elements (roofs, walls and floors) of a layer of insulating material, with increasing thickness as the years went by following the continuous decrease in regulations of the maximum transmittances allowed for building packages. For all four types of building, the floors (horizontals and roofing) are built with a load-bearing part in brick, a layer of insulating material and finally a concrete slab; the walls are usually built with perforated bricks and a layer of insulating material, between the bricks or in the external part, where thin associated with an air space; in multi-apartment buildings there is also the use of concrete walls, again with insulation, sometimes prefabricated. In the case of windows and doors, double-glazing with an air gap (sometimes low-emissivity) became predominant; the wooden frame remained the most commonly used, but in ABs aluminium frames began to be widely used, with the subsequent introduction of thermal break to limit dispersion.

In Slovenia there are no significant changes compared to the previous period: for walls, in SFH and TH the predominant use of perforated bricks with insulation in between remains, while in MFH and AB there is extensive use of solid concrete walls, this time with the addition of heat-insulating material on the outer side; for floors, the most commonly used structure is concrete (without lightening) with insulation and concrete slab, with the exception of the roofs of SFH and TH where the use of insulated wooden roofs remains. Typically, wooden windows and doors with double glazing find some variation in TH where the frame is made of aluminium and in AB where PVC windows and doors are introduced.

Figure 23 summarises the relevant information derived from this analysis.

The interventions suggested for energy efficiency remain the same as those already stated for the previous phases with slight variations: instead of introducing insulation, it is necessary to increase it, either by adding to what already exists or by removing, where possible, what is already there and applying new insulation according to the transmittance requirements to be achieved; for these buildings, compared to those of previous eras, participation in district heating projects makes more sense.

COUNTRY	TYPOLOGY	WINDOWS		EXTERNAL WALLS MATERIAL	INSULATION PRESENCE	HEATING SYSTEM	DHW SYSTEM
		FRAME	GLASS				
SLO	SFH	Aluminium with thermal break	Double	Hollow bricks with insulated cavity	☒ ext. walls ☒ floors ☒ roof	Traditional gas boiler in unheated space	Gas boiler in heated space
	TH	Wood	Double	Hollow bricks with external insulation	☒ ext. walls ☒ floors ☒ roof	Traditional gas boiler in unheated space	Gas boiler in heated space
	MFH	PVC with thermal break	Double	Concrete with external insulation	☒ ext. walls ☒ floors ☒ roof	District heating from unheated gas heating station	Autonomous, gas boiler in heated space
	AB	Wood	Double	Concrete with external insulation	☒ ext. walls ☒ floors ☒ roof	District heating from unheated gas heating station	Autonomous, gas boiler in heated space
ITA	SFH	Wood	Double	Hollow bricks with insulated cavity/external insulation	☒ ext. walls ☒ floors ☒ roof	Traditional gas boiler in unheated space, insulated pipes	Combined with HS, with recirculation / instant gas boiler, without recirculation
	TH	Wood	Double	Hollow bricks with insulated cavity/external insulation	☒ ext. walls ☒ floors ☒ roof	Traditional gas boiler in unheated space, insulated pipes	Combined with HS, with recirculation / instant gas boiler, without recirculation
	MFH	Metal or wood	Double	Hollow bricks or concrete with external insulation	☒ ext. walls ☒ floors ☒ roof	Autonomous/centralized with traditional gas boiler in unheated space, insulated pipes	Autonomous, instant gas boiler, without recirculation
	AB	Metal with or without thermal break	Double	Hollow bricks or concrete with external insulation	☒ ext. walls ☒ floors ☒ roof	Autonomous/centralized with traditional gas boiler in unheated space, insulated pipes	Autonomous, instant gas boiler, without recirculation

Figure 23: Summary table for period 3 buildings

4.2.4 – Period 4

Since the 2000s, a progressive orientation towards functional but, above all, performance-oriented buildings has been noted, thanks to the development of new materials and new construction techniques, but also due to the continuous evolution of regulations to ensure a sustainable construction sector: this has resulted in new materials with good thermal capacity, construction packages and windows and doors designed meticulously to limit heat loss (as well as moisture problems). In the typology matrix of the TABULA programme for the Slovenian state there are no indications of the specific characteristics of the most commonly used window and door frames and construction packages in the 2000s, the normative limit transmittances for different periods are also given.

For Italy, on the other hand, there is a declination, for the four types of building, of the construction characteristics: first of all, a considerable increase in the thickness of the insulating layer is observed, compared to the buildings of the previous period, both in the floors, still in brick, and in the walls, in combination with more innovative hollow bricks, with high thermal resistance, or with concrete panels. For windows and doors, the most commonly adopted solution is a wooden frame with double glazing, with a cavity filled with air or gas, often treated to ensure low emissivity.

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Figure 24 summarises the relevant information derived from this analysis.

COUNTRY	TYPOLOGY	WINDOWS		EXTERNAL WALLS MATERIAL	INSULATION PRESENCE	HEATING SYSTEM	DHW SYSTEM
		FRAME	GLASS				
SLO	SFH	Aluminium with thermal break	Double	Hollow bricks with insulated cavity	☒ ext. walls ☒ floors ☒ roof	Gas condensing boiler in heated space	Combined with HS, with recirculation
	TH	Wood	Double	Hollow bricks with external insulation	☒ ext. walls ☒ floors ☒ roof	Gas condensing boiler in heated space	Combined with HS, with recirculation
	MFH	PVC with thermal break	Double	Concrete with external insulation	☒ ext. walls ☒ floors ☒ roof	District heating from heated gas generation station	District heating, combined with HS
	AB	Wood	Double	Concrete with external insulation	☒ ext. walls ☒ floors ☒ roof	District heating from heated gas generation station	District heating, combined with HS
ITA	SFH	Wood	Double, low-emissive	Hollow bricks with external insulation	☒ ext. walls ☒ floors ☒ roof	Gas condensing boiler in unheated space, insulated pipes	Gas condensing boiler, with recirculation
	TH	Wood	Double, low-emissive	Hollow bricks with external insulation	☒ ext. walls ☒ floors ☒ roof	Gas condensing boiler in unheated space, insulated pipes	Gas condensing boiler, with recirculation
	MFH	Wood	Double, low-emissive	Hollow bricks or concrete blocks with external insulation	☒ ext. walls ☒ floors ☒ roof	Centralized with gas condensing boiler in unheated space, insulated pipes	Autonomous, instant gas condensing boiler, without recirculation
	AB	Wood	Double, low-emissive	Hollow bricks or concrete blocks with external insulation	☒ ext. walls ☒ floors ☒ roof	Centralized with gas condensing boiler in unheated space, insulated pipes	Autonomous, instant gas condensing boiler, without recirculation

Figure 24: Summary table for period 4 buildings

These buildings require much less intervention than their predecessors and, very often, most of the improvements recommended in the sections on other periods are already implemented in the building design. It remains valid that there will always be a continuous evolution, for example, in the regulatory limits to be respected for envelope transmittances, so interventions will also be necessary on these buildings, perhaps even in the short term: one can speak for example of the application of films on transparent closures to increase performance or introduction of shading systems. Also with regard to installations, it will soon be necessary to replace gas generators with heat pumps or renewable sources, and many of these buildings are equipped with them.

4.2.5 - Circularity in interventions

Although our study is not based exclusively on energy efficiency, this is in any case a way of improving the circularity of buildings, even if only from an energy point of view; many of the operations involve increasing the insulation of building elements, replacing windows, doors and thermal systems: circularity can be made to fit within all of these operations by means of the circularity strategies identified in the previous sections of this report.

For example:
- the removal of existing elements must be done carefully, to ensure easy separation and, where possible, recycling;
- in the installation of insulation packages, solutions can be opted for which facilitated separation arrangements are defined;
- the preference should be for implants with renewable energy sources;
- the choice of materials for which environmental certification is provided or which are produced from reused or recycled material.

All the strategies identified in Chapter 2 for the entire supply chain remain valid: in the case of substantial building interventions, as noted to be those on buildings from the years before the 1980s, i.e. a large part of the existing buildings, the SP will have to be followed starting from the end-of-life phase and cascading through the subsequent ones.

CAP. 5 – BEST PRACTICES GAPS IN EU PROJECTS

For greater completeness in providing an overview of how the circular paradigm is currently translated within the construction sector, an analysis of the projects, either ongoing or completed in the last decade, which, at a European level, have had or have as their objective the circularity of buildings and, in general, of the construction supply chain, was carried out alongside the bibliographic research. Questa si è ritenuta utile per identificare per quali best practices ci siano ancora dei gap, a livello europeo ma anche transfrontaliero, nella ricerca e nella sperimentazione.

5.1 – CIRCULAR ECONOMY PROJECTS RESEARCH

An initial search was carried out on the CORDIS database, which gathers all EU Research & Development projects: for the FP7, Horizon 2020 and Horizon Europe programmes, the pages of the projects that met the filters applied for the search were consulted, as in Figure 25, and 38 were selected from more than 4400.

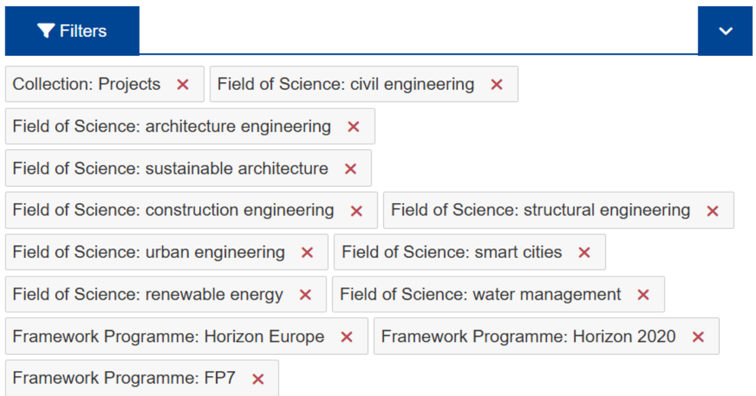

Figure 25: Filters applied for searching the Cordis database

A second phase of research involved Interreg projects: the pages of all 86 EU-funded programmes were consulted and, of these, projects were selected that focused, or are still focusing, on the construction sector and the possibilities of reducing its impact in terms of resource consumption and waste and emission production for the economic circularity of the sector; in total, 20 projects were selected as relevant for research.
Table 2 shows, for each European programme sampled, the number of projects focusing on the application of EC principles in the construction sector.
In total, there were 58 projects deemed of interest because they focused on the introduction of the circular paradigm within the construction sector; following consultation of the dedicated websites, for each the relevant data collected was:

- The status of the project, i.e. whether it was ongoing, or already completed, so as to identify trends in the study of the EC topic;
- The country of origin of the Lead Partner, as well as the presence among the other partners of public or private bodies, universities, research centres or enterprises belonging to the Italian and/or Slovenian territories;
- The objectives, in order to associate to each project, the best practice of focus among those 15 of circularity identified in the previous activities, as well as any others involved even only partially.

Table 2: EU building circularity project by programme

Programme	N. projects CE	Projects
FP7	0	
Horizon 2020	23	INNOFIXX [96]; OptArch [97]; HISER [98]; SUNRISE [99]; Ramp-PV [100]; ReCreate [101]; MOGU floor [102]; RE_CREATE [103]; DRIVE 0 [104]; RE-CREATE [105]; PVadapt [106]; ICEBERG [107]; BIMcert [108]; HEART [109]; BIM-SPEED [110]; BIMERR [111]; BUS-GoCircular [112]; iclimabuilt [113]; PLUG-N-HARVEST [114]; REBECCA [115]; IDEAS [116]; BIPVBOOST [117]; HOUSEFUL [118]
Horizon Europe	15	FibReLoop [119]; RENplusHOMES [120]; CIRCULess [121]; SUM4Re [122]; INBUILT [123]; TIMBERHAUS [124]; WoodStock [125]; GreeNest [126]; Demo-BLog [127]; DISCOVER [128]; RECONMATIC [129]; CIRCOFIN [130]; EASI ZERo [131]; Exploit4InnoMat [132]; MASS-IPV [133]
Interreg Alpine Rhine-Lake Constance-High Rhine	0	
Interreg Aurora	0	
Interreg Baltic Sea Region	0	
Interreg Central Europe	1	ReBuilt [134]
Interreg Danube Region	1	CircularDigiBuild [135]
Interreg Europe	4	KARMA [136]; CONDEREFF [137]; ZEROCO2 [138]; MonitorEE [139]
Interreg France - Italia ALCOTRA	0	
Interreg France - Wallonie - Vlaanderen	1	RENVERSC [140]
Interreg Grande Région	0	
Interreg IPA ADRION	0	
Interreg IPA CBC Italy - Albania - Montenegro	1	ENEA [141]
Interreg IPA Croatia - Bosnia and Herzegovina - Montenegro	1	CrossWaste [142]
Interreg Italia - Osterreich	1	ATTENTION [143]
Interreg Italy – France (Maritime)	1	CIRCULA [144]
Interreg Italy - Slovenija	1	Circular.Buildings [145]
Interreg North Sea	3	BBoBB [146]; CircleBIM [147]; CTB [148]
Interreg North-West Europe	4	CHARM [149]; PREUSE [150]; CIRCULAR RENO [151]; DDC [152]
Interreg Sudoe	0	
Interreg Vlaanderen-Nederland	1	Learning network of biobuilders [153]

The information of interest has been collected in the table in Figure 26; please note that the colours have been associated in this way:

- Green highlights projects in which one of the partners is from Italy;
- In light blue are highlighted the projects in which one of the partners comes from Slovenia;
- In orange are highlighted the projects in which both Italian and Slovenian partners are present.

The last two columns are dedicated to the identifying letters of the best practices, as assigned to their descriptions in the previous section; in the column dedicated to "other practices", all the strategies that emerged in the project analysis are listed, regardless of the relevance given to them compared to the others: this choice was made in order to identify a general picture of where the stakeholders' interest in the construction sector circularity is more or less directed.

Subsequently, the table in Figure 27 was drawn up to carry out a co-occurrency analysis between best practices, in order to understand how the relationships between different strategies are interpreted in more practical contexts such as projects, as opposed to the numerous intersections that appear in the literature, complex to be analysed in a comprehensive manner. The table is constructed by placing on the vertical axis the best practice recognised as the focus of the project, while on the horizontal axis the others mentioned in the project are assigned; The colour legend is the same as that used for Figure 26. Observing the matrix that has been formed, one notices the combinations of the most common practices, so one understands that in the application of one it is important to also implement the other in order to maximise circularity; firstly, the link between the circularity of materials and the use of biobased materials is relevant: this relationship was expected since with the first principle one intends to favour the circulation of materials in the technical cycle, while with the second the biological cycle (e.g.[105], [123], [124]), that is, the two paths that can be followed for the principles of the circular economy. For the continuous circulation of materials in the technical cycle, the use of digital technologies to know their life course or to monitor their performance, such as the use of BIM modelling or sensors (e. g. [97], [98]) but also the participation in databases and collaborative platforms (e. g.[106], [142]) to sell and buy reusable materials, appears to be crucial.
In material-efficient design, the use of digital technologies, such as the use of software for design or 3D moulding to minimise waste (e.g. [96], [128]), is also used.
The last relevant, and expected, correlation is between design for energy efficiency and the use of renewable energy sources: these two are in fact very often considered together, as it is now widely accepted that energy needs, once minimised, should be covered as much as possible through, for example, photovoltaic production; in these projects (e.g. [115], [116]) great importance is precisely given to photovoltaic modules and the possibility of integrating them intensively into buildings.

Code	Project title	Programme	Status	Coordinator's country	Focus Best Practice	Other practices
INNOFIXX	Development of a high quality stainless steel dowel for easy renovation and construction in façades, thermal insulation and solar panels sub-sectors	Horizon 2020	Completed - Aug.2017	Germany	A	B, E
OptArch	Optimization Driven Architectural Design of Structures	Horizon 2020	Completed - Jan.2020	Greece	A	H
KARMA	Circular Economy in the Construction Sector - Acting Today for a Better Future	Interreg Europe	Ongoing	Germany	A	B, H, I
HISER	Holistic Innovative Solutions for an Efficient Recycling and Recovery of Valuable Raw Materials from Complex Construction and Demolition Waste	Horizon 2020	Completed - Jan.2019	Spain	B	D, H, K
CHARM	Circular Housing Asset Renovation & Management	Interreg North-West Europe	Completed - Jan.2024	Netherlands	B	C
CONDEREFF	Construction & demolition waste management policies for improved resource efficiency	Interreg Europe	Completed - May.2023	Spain	B	
SUNRISE	MultiSensor sorting tools in a circular economy approach for the efficient recycling of PVB interlayer material in high-quality prodUcts from laminated glass coNstRuction and demolItion waStEs	Horizon 2020	Completed - Nov.2024	Spain	B	H
Ramp-PV	Raw material up-cycling for circular PV	Horizon 2020	Completed - Oct.2022	France	B	M
ReCreate	Reusing precast concrete for a circular economy	Horizon 2020	Ongoing	Finland	B	
FibReLoop	Closing the fibre-reinforced composites loop: recycling materials for recycled components	Horizon Europe	Ongoing	Italy	B	
RENplusHOMES	Renewable ENergy-based Positive Homes	Horizon Europe	Ongoing	Italy	B	H, I, L, M
CIRCULess	UpCycling mIneral and timbeR-based waste from Construction & manUfacturing process industries through eco-design, advanced logistics, quality control and digital solutions	Horizon Europe	Ongoing	Norway	B	C, J
SUM4Re	Creating materials banks from digital urban mining	Horizon Europe	Ongoing	Spain	B	H
CrossWaste	Enhancing Cross-Border Waste Management through Sustainable Practices	Interreg IPA Croatia - Bosnia and Herzegovina - Montenegro	Ongoing	Croatia	B	
PREUSE	Public Responses to Enable the Use of Salvaged building Elements	Interreg North-West Europe	Ongoing	Belgium	B	I
Learning network of biobuilders	Ecological construction with new materials (such as bio composites) by means of energy-efficient technologies can make a major contribution to climate objectives and at the same time stimulate the local econom	Interreg Vlaanderen-Nederland	Completed - Dec.2022	Netherlands	C	D
MOGU floor	Natural-Grown Flooring for Circular Buildings	Horizon 2020	Completed - Mar.2021	Italy	C	B
RE_CREATE	Eco-innovative building products for sustainable construction	Horizon 2020	Completed - Sep.2019	Israel	C	F
INBUILT	Innovative bio/geo-sourced, re-used and recycled Products coupled with BIM-based digital platform for very low carbon construction, circular economy, energy and resource efficiency	Horizon Europe	Ongoing	France	C	B, D, H
TIMBERHAUS	Climate-smart, circular, and sustainable solutions for use of wood in the construction sector	Horizon Europe	Ongoing	Denmark	C	B, H
WoodStock	Empowering climate-smart, circular, and zero-waste use of underutilized wood from the forest and building stock in the construction sector to support the New European Bauhaus	Horizon Europe	Ongoing	Belgium	C	B
BBoBB	Building Based on Biobased	Interreg North Sea	Ongoing	Netherlands	C	
CIRCULAR RENO	Developing biobased & recycled / reused material solutions for retrofit	Interreg North-West Europe	Ongoing	Netherlands	C	L
DRIVE 0	Driving decarbonization of the EU building stock by enhancing a consumer centred and locally based circular renovation process	Horizon 2020	Completed - Dec.2023	Netherlands	D	A, H
RE-CREATE	Eco-innovative building products for sustainable construction in a circular economy	Horizon 2020	Completed - Jun.2022	Israel	D	B, C, L
GreeNest	NEST InGrained ecosystem foR zEro EmissioN buildings	Horizon Europe	Ongoing	Greece	D	
DDC	Digital Deconstruction - Advanced Digital Solutions Supporting Reuse and High-Quality Recycling of Building Materials	Interreg North-West Europe	Completed - Sep.2023	Netherlands	E	B, H
PVadapt	Prefabrication, Recyclability and Modularity for cost reductions in Smart BIPV systems	Horizon 2020	Completed - Mar.2022	Belgium	F	A, B, M
ICEBERG	Innovative Circular Economy Based solutions demonstrating the Efficient recovery of valuable material Resources from the Generation of representative End-of-Life building materials	Horizon 2020	Completed - Apr.2024	Spain	H	B, I
BIMcert	BIMcert – 1. Construction skills, 2. Energy efficiency, 3. Regulating supply chains, 4. Tackling climate change	Horizon 2020	Completed - Jan.2020	United Kingdom	H	
HEART	Holistic Energy and Architectural Retrofit Toolkit	Horizon 2020	Completed - Jul.2022	Italy	H	L
BIM-SPEED	Harmonised Building Information Speedway for Energy-Efficient Renovation	Horizon 2020	Completed - Oct.2022	Germany	H	L
BIMERR	BIM-based holistic tools for Energy-driven Renovation of existing Residences	Horizon 2020	Completed - Sep.2022	Germany	H	L
Demo-BLog	Development and Demonstration of Digital Building Logbooks	Horizon Europe	Ongoing	Netherlands	H	
DISCOVER	Digital, autonomous, Intelligent and Synchronous system for Continuous identification, Optimization and Value Extraction of Resources from the end-of-use built environment	Horizon Europe	Ongoing	Spain	H	E
RECONMATIC	Automated solutions for sustainable and circular construction and demolition waste management	Horizon Europe	Ongoing	Czech Republic	H	A, B, I
ReBuilt	Circular and digital renewal of central Europe construction and building sector	Interreg Central Europe	Ongoing	Slovenia	H	C, I, J
CircularDigiBuild	Boosting the uptake of emerging technologies in circular economy implementation in construction and buildings industry in Danube region to sustainably harness the twin transition for greener future	Interreg Danube Region	Ongoing	Bulgaria	H	
CircleBIM	Public Sector Innovation with BIM for a more circular construction sector	Interreg North Sea	Ongoing	Germany	H	
CIRCOFIN	Circular Construction Finance	Horizon Europe	Ongoing	Spain	I	B, H
ATTENTION	The aim of the ATTENTION project is to promote the circular economy in construction by identifying the needs and expectations of innovative tools/services for SMEs. It will develop a cross-border catalogue of affordable services and tools and create a HUB network that will provide specialised services and support to companies and support sustainable innovation in the building value chain.	Interreg Italia - Osterreich	Ongoing	Italy	I	
CIRCULA	Rafforzamento delle competenze a supporto dei modelli di economia circolare e lo scambio di buone pratiche per le imprese della filiera mediterranea dell'edilizia sostenibile	Interreg Italy - France (Maritime)	Ongoing	Italy	I	
Circular.Buildings	A greener, low-carbon transitioning towards a net zero carbon economy and resilient Europe by promoting clean and fair energy transition, green and blue investment, the circular economy, climate change mitigation and adaptation and risk prevention and management.	Interreg Italy - Slovenija	Ongoing	Italy	I	
CTB	Circular Trust Building - Promoting the transition to a circular, resource-efficient economy in the building sector.	Interreg North Sea	Ongoing	Netherlands	I	B
ZEROCO2	Promotion of near zero CO2 emission buildings due to energy use	Interreg Europe	Completed - Mar.2020	Slovenia	L	M
ENEA	ENergy Efficiency living lAb	Interreg IPA CBC Italy - Albania - Montenegro	Completed - 2021	Italy	L	I
BUS-GoCircular	Stimulate demand for sustainable energy skills with circularity as a driver and multifunctional green use of roofs, façades and interior elements as focus.	Horizon 2020	Completed - Feb.2024	Netherlands	L	
iclimabuilt	Functional and advanced insulating and energy harvesting/storage materials across climate adaptive building envelopes	Horizon 2020	Completed - Feb.2025	Greece	L	
PLUG-N-HARVEST	PLUG-N-play passive and active multi-modal energy HARVESTing systems, circular economy by design, with high replicability for Self-sufficient Districts Near-Zero Buildings	Horizon 2020	Completed - Nov.2022	Greece	L	M
REBECCA	Renovating the Existing Buildings Environment through the Combination of Circular economy and the Add-ons' strategy	Horizon 2020	Ongoing	Germany	L	
EASI ZERo	Envelope mAterial System with low Impact for Zero Energy buildings and Renovation	Horizon Europe	Ongoing	France	L	B, C, D
Exploit4InnoMat	An Open Innovation Ecosystem for exploitation of materials for building envelopes towards zero energy buildings	Horizon Europe	Ongoing	Greece	L	H
MonitorEE	Improving energy efficiency through smarter management systems	Interreg Europe	Ongoing	Spain	L	I
RENVERSC	Efficient Renovation towards Circularity	Interreg France - Wallonie - Vlaanderen	Ongoing	Belgium	L	I
IDEAS	Novel building Integration Designs for increased Efficiencies in Advanced Climatically Tunable Renewable Energy Systems	Horizon 2020	Completed - Apr.2023	Ireland	M	L
BIPVBOOST	Bringing down costs of BIPV multifunctional solutions and processes along the value chain, enabling widespread nZEBs implementation	Horizon 2020	Completed - May.2023	Spain	M	L
MASS-IPV	Enabling Massive Integration of PV into Buildings and Infrastructure	Horizon Europe	Ongoing	Germany	M	
HOUSEFUL	Innovative circular solutions and services for new business opportunities in the EU housing sector	Horizon 2020	Completed - Apr.2023	Spain	O	B, H, K, L, N

Figure 26: Database of selected CE projects

↓ Focus Best Practice	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
A		INNOFIXX; KARMA			INNOFIXX			OptArch; KARMA	KARMA						
B		CONDEREFF; ReCreate; FibReLoop; CrossWaste	CHARM; CIRCULess	HISER				HISER; SUNRISE; RENplusHOMES; SUM4Re	RENplusHOMES; PREUSE	CIRCULess	HISER	RENplusHOMES	Ramp-PV; RENplusHOMES		
C		MOGU floor; INBUILT; TIMBERHAUS; WoodStock	BBoBB	Learning network of biobuilders; INBUILT		RE_CREATE		INBUILT; TIMBERHAUS				CIRCULAR RENO			
D	DRIVE 0	RE-CREATE	RE-CREATE	GreeNest				DRIVE 0				RE-CREATE			
E		DDC						DDC							
F	PVadapt	PVadapt											PVadapt		
G															
H	RECONMATIC	ICEBERG; RECONMATIC	ReBuilt		DISCOVER			BIMcert; Demo-BLog; CircularDigiBuild							
I		CIRCOFIN; CTB						CIRCOFIN	ATTENTION; CIRCULA; Circular.Buildings						
J															
K															
L		EASI ZERo	EASI ZERo	EASI ZERo				Exploit4InnoMat	ENEA; MonitorEE; RENVERSC			BUS-GoCircular; iclimabuilt; REBECCA	ZEROCO2; PLUG-N-HARVEST		
M												IDEAS; BIPVBOOST	MASS-IPV		
N															
O		HOUSEFUL						HOUSEFUL			HOUSEFUL	HOUSEFUL		HOUSEFUL	

Figure 27: Co-occurrency projects matrix

5.2 – BEST PRACTICES GAPS

A final analysis of the European projects was focused on those in which Italian and/or Slovenian partners are involved: although the only way to highlight the actual gaps in the circular transition is by gathering the opinions and experiences of stakeholders in the sector, a study of the projects can be used to identify which aspects of circularity applicable to construction are more or less of interest to study groups, companies and bodies directly involved.
To do this, the table in Figure 28 has been created in which, for each of the 15 best practices identified in Chapter 3, the EU projects on the EC have been placed in three columns respectively for the presence of Italian, Slovenian or both partners; in red are written the projects for which the best practice in the corresponding row is the focus, while in grey the others in which it is of secondary importance.

↓ Focus Best Practice	ITALY	SLOVENIA	ITALY-SLOVENIA	TOTAL N. OF PROJECTS FOR EACH BP
A	OptArch; KARMA; PVadapt; RECONMATIC		DRIVE0	5
B	CONDERFF; FibReLoop; HISER; RENplusHOMES; SUNRISE; KARMA; MOGUfloor; TIMBERHAUS; Pvadapt;ICEBERG; RECONMATIC; EASI ZERo; HOUSEFUL	WoodStock		14
C	MOGU floor; TIMBERHAUS	WoodStock	ReBuilt	4
D	GreeNest; EASI ZERo		DRIVE 0	4
E				0
F	Pvadapt			1
G				0
H	ICEBERG; RECONMATIC; OptArch; KARMA; HISER; SUNRISE; RENplusHOMES; TIMBERHAUS; Exploit4InnoMat; HOUSEFUL	CircularDigiBuild	ReBuilt; DRIVE 0	13
I	ATTENTION; KARMA; RENplusHOMES; ENEA		Circular.Buildings	5
J				0
K	HISER; HOUSEFUL			2
L	EASI ZERo; ENEA; Exploit4InnoMat; iclimabuilt; RENplusHOMES; IDEAS; BIPVBOOST; HOUSEFUL		ZEROCO2	9
M	BIPVBOOST; IDEAS; MASS-IPV; RENplusHOMES; Pvadapt		ZEROCO2	6
N	HOUSEFUL			1
O	HOUSEFUL			1

Figure 28: Projects with Italian / Slovenian partners by Best Practice

By counting the total number of items for each row, a quantification of the number of projects with cross-border partners in which the importance of the relevant best practice is recognised was obtained.

It is evident that the focus is predominantly on the circularity of materials (B) and the use of digital technologies (H) within projects: these two practices were also among the most recognised in the literature, so the figure is in line with what was expected.

The same observation also applies to the third practice involved in more than one project, namely design for energy efficiency (L): in the previous chapter analysing the cross-border built heritage the need for the energy requalification of existing buildings in Italy and Slovenia has already been abundantly addressed, so the participation in projects aimed at identifying new circular solutions for these interventions is reassuring.

Moderate interest is directed towards practices directly involving the limitation of the use of virgin materials and the minimisation of the environmental impact related to the production and disposal of materials, starting with material-efficient design (A); among bio-based materials (C), the focus, especially in Slovenia, is on wood, whose environmental qualities are recognised as well as its structural ones: In view of the wide availability of the material in the cross-border context, this practice is mixed with the principle of the use of local materials, which falls under practice D, i.e. the use of low-impact materials, which in turn appears to be of cross-border interest.

Also of partial interest is the creation of and participation in platforms for circularity (I): these include the Circular.Building project, which thus creates new opportunities for cross-border stakeholders, and at the same time can become an example to emulate for other European contexts.

While for energy circularity both the practice of design for energy efficiency (L) and the practice of introducing renewable energy sources (M) are addressed in numerous projects, the circularity of water in buildings (N) is practically neglected in European projects; the best practice of water resource management is partially involved in the HOUSEFUL project [118], the only one in which the aim is to improve the circularity of buildings through the use of a quantification system for the circularity and sustainability of the building, in all its aspects. The same project is also one of two that emphasises the integration of Life Cycle Assessment (K) to make informed design choices for circularity. Related to the lack of interest in LCA is also the lack of interest in the drafting and use of product certifications (J): it has already been mentioned that these can only help to improve the circularity of materials, which in any case appeared to be a widespread topic in European projects, so exploring their use could only bring benefits.

Finally, practically no Projects deal with circular design techniques, i.e. Design for Disassembly (E), Design for Adaptability (F) and Design for Durability (G): this result was to be expected, as the transition of the design approach from traditional to circular requires much more effort and training than is needed to integrate the other circularity practices into the construction supply chain. However, precisely because of the difficulty in bringing stakeholders closer to this practice, it would be useful for there to be EU projects that offer guidance or an example for designers in the sector to emulate.

To summarise, of the 58 projects in the EU area, 30 involve cross-border partners: this means that there is an interest in the circular transition of the sector, but this, as we have seen, is concentrated on some aspects, while neglecting others that are also necessary for the implementation of practices that are already more widely recognised for their validity.

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APPENDIX –

BEST PRACTICES CHARACTERISATION SHEETS

CHARACTERISATION OF BEST PRACTICE A

UNIVOCAL CODE	**BP_A**
NAME	MATERIAL-EFFICIENT DESIGN
OBJECT	Materials – Resources – Components
LIFE CYCLE STAGE	Design – Product manufacturing – Construction process
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Training for designers, products availability

1. CHARACTERISTICS

1.1. DESCRIPTION

Material efficiency-oriented design involves adopting design and construction techniques that minimise the production of construction and demolition waste (C&DW), but above all that limit or eliminate the waste of resources, such as energy and water, particularly during the construction phase. This translates into careful design of the different components, but also of the individual construction phases.

1.2. RELEVANCE FOR CIRCULAR BUILDINGS

This practice involves acting in the early stages of the life cycle (planning, design, component production and construction) of the building according to the circular economy principles of Reduce, Refuse and Rethink/Redesign: with this design paradigm, material savings are maximised, with even the possibility of using materials derived from recycling and reuse to increase circularity; in addition, as no excessively complex on-site processing is required, the number of vehicles and handling is reduced, with the associated savings in fossil fuels and emissions. The use of off-site manufactured components also reduces the amount of water that is usually required on-site to complete construction operations.

1.3. INNOVATION ASPECTS

Compared to traditional design techniques, the aim is to move away from on-site production in favour of off-site realisation of components; this leads to a change in the management of logistics and material storage, favouring a just-in-time approach: this increases the precision with which site schedules must be realised. This design philosophy requires a change of mindset in designers and companies, with a greater inclination towards prefabrication. The extensive use of prefabrication brings about considerable changes in the management of logistics and transport on site, but also in the storage of materials and delivery times.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Use of prefabricated components, transported and simply assembled on site
- Standardisation-oriented design and optimisation of building parts
- Use of optimisation software and models as well as digital technologies for component design
- Ad-hoc definition of site configuration
- 3D printing of components to avoid material waste
- Construction of new buildings or parts of buildings only if extremely necessary and if it is not possible in any way to reuse something already constructed
- Drawing up a construction and dismantling plan
- Use of self-healing materials to ensure longevity of structures and reduction in the use of new materials
- Identification of consolidation centres to facilitate the storage of prefabricated materials, even large ones

2.2. Involved stakeholders

- Architects
- Structural designers
- Plant designers
- Construction companies
- Building materials manufacturers

3. Impact

3.1. Benefits

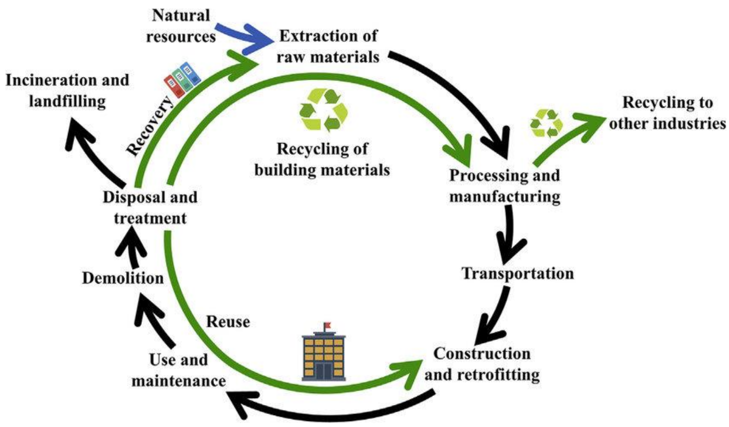
- Reduction of waste produced during construction on site
- Simpler and faster work on site, with less waste of energy and water
- Optimised structures that are not excessively heavy, simplifying assembly and disassembly operations
- Reduced environmental impact in terms of emissions due to optimised use of resources and materials
- No need to draw up plans for on-site waste management, including waste separation and the resulting logistics
- Reduction of waste in material logistics due to consolidation centres, especially in terms of fuel and packaging

3.2. Complexities

- Need for experienced professionals able to operate according to multi-parameter optimisation schemes
- Problems from the point of view of both transport and on-site storage of prefabricated parts, especially large ones
- Much more laborious and complex design phase, characterised by numerous attempts and changes to layouts
- Design of the prefabricated modules considering their intersections with the various services
- Waste of material originated by necessary changes on site as a result of design errors, which negates the efficiency of prefabrication
- Inability to realise overly complex and articulated designs

CHARACTERISATION OF BEST PRACTICE B

UNIVOCAL CODE	**BP_B**
NAME	MATERIAL CIRCULARITY
OBJECT	Materials – Resources – Components
LIFE CYCLE STAGE	Design – Product manufacturing – Construction process - Refurbishment – End of life
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Market availability, regulation and performance compliance



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1. Characteristics

1.1. Description

This best practice in circular building design involves limiting the use of virgin raw materials and instead increasing the reuse of components of buildings that are no longer used or recycled materials, at least to a certain percentage. No less important is the planning of waste management at the end-of-life of building/plant components, with the evaluation of possible circularity alternatives for them, i.e. reuse, recovery or recycling, with up-cycling or down-cycling.

1.2. Relevance for circular buildings

The circularity of technical materials is the basis of the circular economy approach: it allows the introduction of all the 9R principles into the building supply chain: in the planning and design phases of the building it is necessary on the one hand to prefer reusable and recycled materials over virgin ones, and on the other hand to design so that at the end of their useful life they in turn can be recovered and put back into circulation. Refurbishment or repurpose may be necessary if entire components are to be reused, instead recycle and recover if they are no longer able to guarantee sufficient performance.

1.3. Innovation aspects

The circularity of construction materials is currently very limited, with an excessive and no longer sustainable production of construction and demolition waste: the environmental benefit of material circularity is obvious, but the cost of reused materials is usually higher, so the economic advantage of choosing virgin materials prevails. With this in mind, a systematic change of the whole sector is needed, leading to an overall lowering of costs, benefiting all companies involved, except clearly those involved in extraction and disposal of products, i.e. the least sustainable.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Re-use of materials from the demolition of old buildings with the same or a different function
- Use in new buildings of entire components from the dismantling of other buildings (e.g. windows and doors)
- Design of materials with a view to recycling, reuse or maximisation of useful life to minimise waste
- Production of easily demountable components to facilitate recycling
- Use of design techniques such as Design for Disassembly
- Compliance with CAM
- Use of prefabricated components for which a disassembly and waste management scheme is already established
- Attention to compliance with the Waste Framework Directive at European level
- Co-operation with other stakeholders in the sector for the circulation of materials
- Search for products in reuse markets, at companies that refurbish products or use recycled products as a basis

2.2. Involved stakeholders

- Architects
- Structural designers
- Plant designers
- Construction companies
- Demolition companies
- Other construction companies
- Plant installers/maintainers
- Window fitters
- Flooring companies
- Building materials manufacturers
- Manufacturers of plant components
- Public administrations

3. Impact

3.1. Benefits

- Minimisation of virgin raw materials extracted for new materials
- Reduction in the amount of materials that become waste, leading to their abandonment in landfills
- More possibilities to achieve building sustainability certifications
- Better LCA results on components or the whole building in terms of impact, as well as better scores in circularity indices
- Access to incentives and tax breaks
- Boost in research for the re-use of materials for new purposes and uses outside the classical one for which they are produced (e.g. use of demolition waste as aggregates)
- Maximising the life cycle of materials, as much as possible at their maximum value (closing the loop)

3.2. Complexities

- Materials and components not always of sufficient quality to guarantee reuse, even with down-grading
- High cost of companies dealing with disassembly, separation and re-use, as well as storage and transport of parts
- Need for verification of the performance requirements of materials to be reused by specialists
- Lack of confidence on the part of buyers with respect to material guarantees, especially in the absence of material certification
- Limited diffusion of waste treatment and sorting plants on the territory, with the need for long and expensive transports, which cancel out the benefit of reuse
- Easier access to virgin materials than to reuse markets, as well as higher cost of products in these markets
- Complex reverse logistics management

CHARACTERISATION OF BEST PRACTICE C

UNIVOCAL CODE	**BP_C**
NAME	USE OF BIO-BASED MATERIALS
OBJECT	Materials
LIFE CYCLE STAGE	Design – Product manufacturing – End of life
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Market availability, regulation and performance compliance

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1. Characteristics

1.1. Description

Maximum circularity of materials is achieved when they are able to regenerate new virgin materials at the end of their life, not creating any waste, but rather being a new source of material. For this reason, the use of bio-based and natural materials, such as wood, bamboo and raw earth, is to be preferred, whenever possible, to materials that cannot be completely recycled, such as cement mixes. Once decommissioned, these materials are naturally biodegradable and can create compost for fertilising productive land.

1.2. Relevance for circular buildings

The integration of these materials into buildings, whether for structural or non-structural purposes, aligns with the idea of waste prevention, i.e. with the principles of Reduce, Refuse and Rethink: with the choice of natural materials at the planning and design stage, the greatest benefits occur at the end of life, where instead of a loss of value as with technical materials, there is an increase in value as they contribute to the generation of new material.

1.3. Innovation aspects

Rather than an innovative approach, this is a return to more primitive and vernacular building techniques, which are undoubtedly more sustainable than those that have taken hold since the excessive industrialisation of the sector; however, materials of natural origin are now being researched and processed to maximise their benefits and performance, making them as good as traditional ones, with a continuous push towards innovation and the green transition. However, not all building components can be made exclusively from bio-based materials: for those sectors where this is not possible, there must still be an interest in identifying more natural solutions to increase competitiveness.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Use of natural and self-regenerating materials such as: bamboo, cross-laminated timber (CLT), solid wood, cork…
- Dismantling the natural components in the building and using them to generate new material
- Planting of woods and forests from which to draw material
- Choice of bio-based materials also in function of a shorter supply-chain, using timber and other products available in abundance from the construction area
- Reduction of treatments on natural materials to promote their composting
- Use of bio-based polymers
- Checking the environmental sustainability of the use of certain materials found in nature, especially in relation to the consequences on the ecosystems

2.2. Involved stakeholders

- Architects
- Structural designers
- Construction companies
- Demolition companies
- Window fitters
- Flooring companies
- Building materials manufacturers

3. Impact

3.1. Benefits

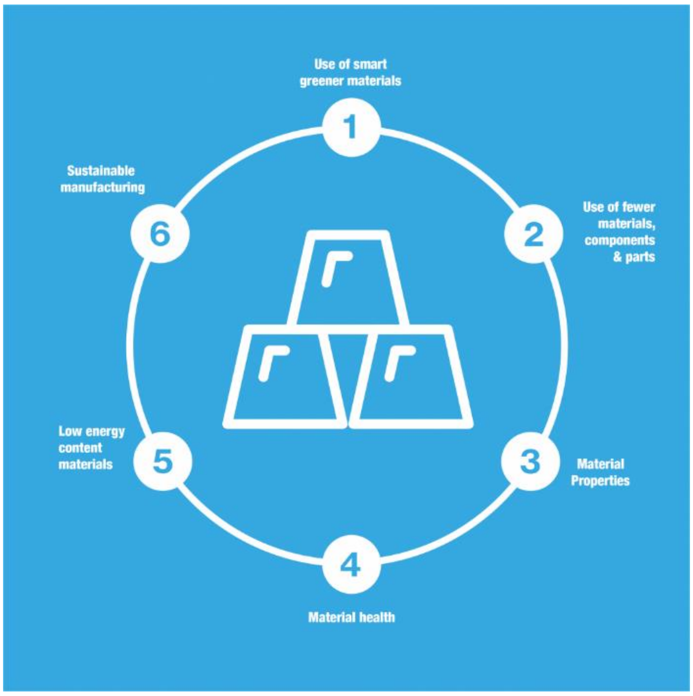
- Absence of waste production because once the material is discarded it is biodegradable or can be composted
- Contribution to the regeneration of the environment instead of only creating negative impacts
- Good predisposition of such materials to prefabrication
- Possibility of building lighter structures or, if used in combination with other structural materials such as reinforced concrete, of partially lightening very massive structures
- Reduction of the embodied carbon of the entire structure
- Simplified design, without the need for overly complex designs (this is referred to as low-tech design), particularly in the case of wood

3.2. Complexities

- Lack of regulatory support and/or adequate guidelines for designers for structures with these materials
- Materials with shorter lifecycles than non-renewable materials such as metal and plastic, with the need for continual replacement that may in the long run be more impactful than the use of other materials
- Reuse of these materials limited to down-grading
- Risk of incorrect or mismanagement of forests and woodlands from which timber is obtained, especially in terms of biodiversity conservation and carbon sequestration
- Greater vulnerability of these materials to weathering and subsequent degradation, requiring more frequent maintenance or replacement

CHARACTERISATION OF BEST PRACTICE D

UNIVOCAL CODE	**BP_D**
NAME	USE OF LOW-IMPACT MATERIALS
OBJECT	Materials – Resources
LIFE CYCLE STAGE	Design – Product manufacturing – End of life
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Market availability, regulation and performance compliance



1. Characteristics

1.1. Description

This best practice consists in abandoning fossil, non-renewable sources, but also those materials for which extraction, processing and transport have a considerable impact in terms of resource consumption and environmental pollution. Materials from neighbouring production sites or materials whose processing is environmentally sound are to be preferred when constructing or working on buildings; materials with a low carbon footprint and those that have a de-carbonising power themselves also fall into this classification.

1.2. Relevance for circular buildings

From this practice of circularity comes a notable change in the way products are chosen: in the construction supply chain, a mentality still prevails based exclusively on economic advantage and cost reduction, whereby products with lower environmental performance are preferred if they are cheaper; these products are usually also those from countries where production is cheaper and therefore the impact of transport, which is very significant, must be considered.

Choosing local materials avoids this unnecessary pollution, but more importantly it triggers a chain reaction that can create local industrial ecosystems based on the circular economy. If the products you need are not available locally, choosing those for which you have the least carbon footprint and resource consumption allows you to align with the Reduce circularity principle.

1.3. Innovation aspects

Many of these products are the result of research and innovation, particularly in the optimisation of the use of resources in the production processes by which they are made. For this reason, the major stakeholders involved in this practice are the manufacturing companies, for which a change in management methods and supply chain philosophy is required. These must also have an interest in creating products with as few harmful emissions as possible, to ensure more possibilities for reuse instead of recycling, especially without health consequences for those involved in the end-of-life phase.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Prefer materials from local manufacturers when designing
- Within a choice between materials with the same guaranteed performance, opt for the lowest environmental impact
- Diffuse low-emission alternative materials, such as low-carbon concrete and steel, self-healing concrete or photocatalytic concrete
- Consider the impact at all stages of the building's life, especially water and energy consumption
- Find out about demolition or decommissioning of buildings in the surroundings to check the opportunity to reuse materials from them
- Supply-chain tracking to quantify the benefit of using local materials over others

2.2. Involved stakeholders

- Architects
- Structural designers
- Plant designers
- Construction companies
- Building materials manufacturers
- Manufacturers of plant components

3. Impact

3.1. Benefits

- Frequent correspondence between low-emissivity and likelihood and/or ease of recycling or reuse of materials
- Reduction very often also of costs related especially to the transport of materials
- Incentive in the development of the regional economy and increased drive for research and innovation by making more and more products available within a small radius
- Low impact, also understood as limited emission of harmful substances, with consequent benefits for both building users and workers involved in any dismantling/demolition operations

3.2. Complexities

- Very often higher cost for materials with less impact than conventional ones

- Lack of local production of materials or plant components, especially in the area of photovoltaics
- Lack of data on the reliability and performance of the most innovative materials does not allow precise impact assessments (e.g. for LCA evaluation)
- Need for more widespread use of these products in construction practices so that they take over from their more impactful alternatives
- Lack of regulatory references for the most innovative materials
- Lack of initiatives by public administrations and local authorities to promote the local circulation of materials

CHARACTERISATION OF BEST PRACTICE E

UNIVOCAL CODE	**BP_E**
NAME	DESIGN FOR DISSASSEMBLY / DEMOLITION / DECONSTRUCTION
OBJECT	Materials – Resources – Components – Whole building
LIFE CYCLE STAGE	Design – Product manufacturing – Construction process – Refurbishment – End of life
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Training for designers, products availability

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1. Characteristics

1.1. Description

Design for Disassembly or Design for Deconstruction is a design practice that involves designing the building, already at an early stage, looking at the end of life, i.e. adopting solutions and drawing up an accurate plan for the disassembly of the structure into its various components. Following this technique it is possible to reuse entire components in other buildings, if the deconstruction is non-destructive, or to recover materials through selective dismantling, if the entire component cannot be removed without damaging it or cannot be used further.

1.2. Relevance for circular buildings

This practice is particularly relevant for the circularity of buildings: by designing the building looking already at its end-of-life phase, all 9 principles of circularity apply. First of all, there is the reduction in the production of construction waste, as the assembly is designed to be quick and easy on site; moreover, this design philosophy ensures the reuse and/or recycling of disparate products and components. In addition, it is a technique that is not only valid for new constructions, but also for intervening locally, on existing buildings, allowing the possible reversibility of the intervention.

1.3. Innovation aspects

This way of designing the building is totally innovative and different from any traditional approach. For this reason, it is necessary for new designers to be trained directly in this philosophy, while the more experienced ones keep up to date and are willing to get involved: in particular, it is necessary to be familiar with digital design tools, such as BIM, which can guarantee disassembly. At the same time, special care is required of supplier companies, especially when it comes to construction products supplied in prefabricated packages, to ensure their disassembly, which may necessitate changes in production lines. Another new aspect arising from Design for Disassembly is the need to introduce into the supply chain a figure or company with expertise in disassembly practices and the logistics of the resulting materials, to be involved from the earliest planning stages.

2. TECHNICAL INFORMATION

Main technical information as given by the literature.

2.1. PRACTICAL APPLICATIONS

- Use of prefabricated elements
- Preference for mechanical joints (bolts, joints...) over chemical joints (gluing, welding)
- Ensure accessibility of connections
- Maintain as much independence as possible between the various components to facilitate disassembly
- Use a basic open building configuration
- Limit the use of finishes and treatments that may compromise the reuse of components and/or recycling of materials
- Drawing up a disassembly plan, indicating the steps (disassembly sequence planning), machinery, handling space and destination of each component or material
- Design and manage the building by layers (site, envelope, structure, services, interior, furniture)

2.2. INVOLVED STAKEHOLDERS

- Architects
- Structural designers
- Plant designers
- Construction companies
- Demolition companies
- Window fitters
- Flooring companies
- Building materials manufacturers
- Manufacturers of plant components

3. Impact

3.1. Benefits

- Limitation in the production of construction and demolition waste by 65-80%
- Possibility of giving a second life to entire building components, in the case of non-destructive dismantling, or, in the worst case, destructive dismantling, to individual materials
- Limitation in the use of virgin raw materials
- Extension of the service life of building parts
- Reduction or elimination of landfill costs of products
- Ease of separation of materials in case transport to landfill is unavoidable

3.2. Complexities

- In the case of chemical joints, disassembly is only possible through the use of solvents or mechanical operations that may compromise the possibility of recycling the material
- Much more complex and time-consuming planning that must go all the way to the end-of-life phase, even providing indications after that time
- Perfect disassembly and component recovery plans only guaranteed through the use of digital technologies such as BIM and digitisation of supply chains
- Need for numerous means and spaces for disassembly and to define precise sequences, also with time indications, in order to avoid interference in the different processes, which are often difficult to respect
- Training of designers needed to instruct them in this design approach
- Disassembly of certain structures, especially steel, more expensive than traditional demolition operations

CHARACTERISATION OF BEST PRACTICE F

UNIVOCAL CODE	**BP_F**
NAME	DESIGN FOR ADAPTABILITY / FLEXIBILITY
OBJECT	Components – Whole building
LIFE CYCLE STAGE	Design – Product manufacturing – Construction process - Operation and use – Refurbishment – End of life
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Training for designers, products availability

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1. Characteristics

1.1. Description

A design aimed at the adaptability and flexibility of the building allows the end of its life to not coincide with the end of its use, also allows, downstream of an initial careful design, to change and vary, with reduced need for means and money, its basic configuration to adapt it to new needs and uses, different from the original ones, even if not identified in the first design of the structure.

1.2. Relevance for circular buildings

This practice is aligned with the circular economy idea of rethinking, redesigning and reusing: all these principles are involved in the design phase to prevent the production of construction and demolition waste, not considering the possibility that the building, at the end of its first useful life, has to be dismantled, but instead reused in its entirety and with only minimal changes. Buildings resulting from design for adaptability/flexibility are thus a guarantee that material flows will be reduced even in the case of interventions on them.

1.3. Innovation aspects

This way of designing the building is totally innovative and different from any traditional approach. For this reason, it is necessary for new designers to be trained directly in this philosophy, while the more experienced ones keep up to date and are willing to get involved: in particular, it is necessary to be familiar with digital design tools, such as BIM, which can guarantee to keep track of what can be done and what has already been done. The idea that a building can be easily reused by changing its use is in contrast to one of today's major problems, namely that of the impossibility of recovering disused existing buildings without incurring structural and economic problems; however, it is also necessary here for companies to focus on the transition to standardised components, which also allow other construction product companies to adapt production and integrate to maximise building flexibility.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Use of modular and/or prefabricated components
- Structural configuration of the building as regular and simple as possible
- Easily maintainable and adaptable elements
- Use of digital modelling software (e.g. BIM)
- Realisation of several design alternatives with the same components to provide a range of easily realisable configurations
- Drawing up design drawings as detailed and accurate as possible, also paying attention to how parts are joined together
- Need to emphasise in the designs which parts must remain fixed in subsequent interventions to avoid problems, especially structural ones, such as entrances, openings, technical compartments and inspection areas, in order to always guarantee accessibility
- Use of movable partitions and components
- Design and management of the building by layers (site, envelope, structure, services, interior, furniture)

2.2. Involved stakeholders

- Architects
- Structural designers
- Plant designers
- Construction companies
- Other construction companies
- Building materials manufacturers
- Manufacturers of plant components

3. Impact

3.1. Benefits

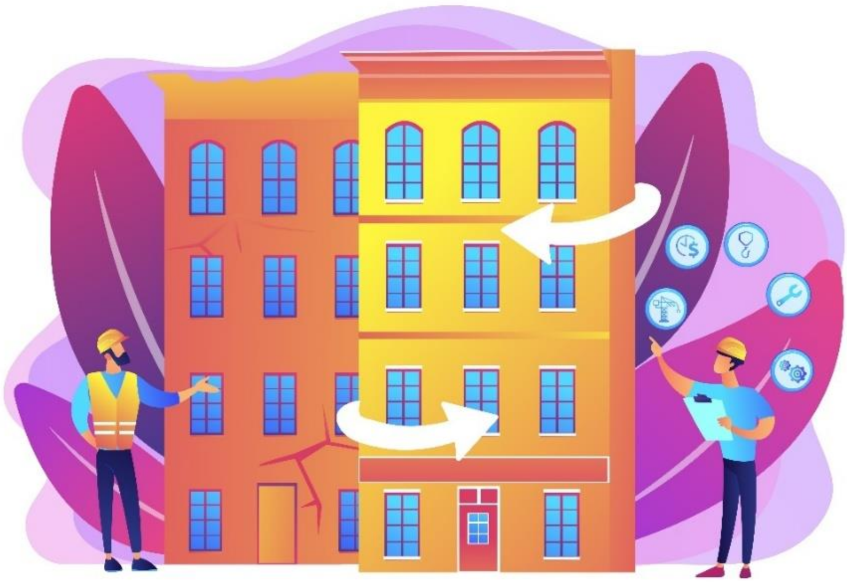
- Limitation of construction and demolition waste production by 83.2%.
- Possibility of easy reversibility of design choices if they are not as functional as initially expected
- Extension of the useful life of the building with the possibility of changes of use according to new requirements, be they aesthetic, functional or spatial, without excessive complications and costs
- Easier replication, even with slight modifications, of the building for others with the same intended use, simplifying the work of designers and allowing more widespread use of this type of design

3.2. Complexities

- Need for much more accurate and precise component design
- High degree of attention to be paid in the realisation of the various components in total adherence to the design, with minimum tolerances to avoid problems in reconfigurations
- Maximum flexibility achievable through multi-criteria decision-making methods, which are very complex and require a specialised figure
- Unreasoned overuse of means, with reduction of the circularity of the process, resulting from the possibility of easily modifying the building, even at very close time intervals
- Need to design considering every layout variation made on the building in the past, in order to know how the building and in particular the structure has been worked on, devising safe and increasingly circular future scenarios

CHARACTERISATION OF BEST PRACTICE G

UNIVOCAL CODE	**BP_G**
NAME	DESIGN FOR DURABILITY / RESILIENCE / MAINTAINABILITY
OBJECT	Materials – Resources – Components – Whole building
LIFE CYCLE STAGE	Design – Product manufacturing – Construction process -Operation and use – Refurbishment
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Training for designers, products availability



1. Characteristics

1.1. Description

This type of design involves orienting the design towards maximising the useful life of the building or installation without any particular upheaval or change; in particular, the objectives of durability and resilience are achieved by using performance materials that are resistant and able to maintain these characteristics over time, despite use and adverse events. To ensure a long service life it is necessary, at the same time, to facilitate and ensure maintenance of the entire building or its parts, without compromising performance.

1.2. Relevance for circular buildings

Designing the building so that it maintains its function and performance over time, thanks also to facilitated and planned maintenance, makes it possible to avoid the production of construction and demolition waste, except at the end of its useful life, which with this approach is extended to the maximum. At the same time, the use of high-performance materials means that components do not have to be replaced during the building's life cycle; however, if maintenance is no longer sufficient, the capacity-oriented design also makes it possible to replace components identified at an early stage with a useful life shorter than that of the entire building: in this way, disused components can be reused or recycled.

1.3. Innovation aspects

This design approach is similar to the traditional one for buildings with particularly important uses, such as hospitals and universities, or seismic-resistant buildings: the novelty lies in applying the same philosophy to other, more common large buildings, if not to ensure their resilience, then to ensure that their useful life is as long as possible. In this practice, greater attention must necessarily be paid to the drafting of a precise and punctual maintenance plan, but above all to its observance: important is the identification in the design phase of the people involved and the use of digital systems to monitor the need for intervention. Furthermore, manufacturers must invest in research to maintain materials at peak performance for as long as possible, without ever neglecting the aspect of environmental impact, and accompanying the material with all useful maintenance information.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Selection of materials and building/plant components of the highest quality and with guaranteed long-term performance, including maintenance practices to maintain them at a high level
- Adoption of precautions and configurations in the arrangement of structural and plant components so that access for maintenance is guaranteed
- Design always according to the principles of redundancy to ensure continuity of operation and safety even in unfavourable situations
- Design in full compliance with current regulations, both from a structural point of view and for the safety of electrical and fire protection systems
- Simple, symmetrical and regular building configuration
- Drafting of an accurate maintenance plan and projects with exact indication of the areas of intervention
- Special attention to the most fragile parts of the project (e.g. seismic joints)

2.2. Involved stakeholders

- Architects
- Structural designers
- Plant designers
- Construction companies
- Other construction companies
- Plant installers/ maintainers
- Building materials manufacturers
- Manufacturers of plant components

3. Impact

3.1. Benefits

- Reduced cost of repeated component replacement
- Limited amount of waste produced, only at end-of-life
- High safety against isolated and destructive events, such as earthquakes
- Ease of intervention even in structural components, with less need for highly qualified technicians and without the need for destructive intervention in the building to access it
- Maximised guaranteed service life for the entire building and its individual parts
- Less need for optimisation processes for the structure and materials, in favour of a wider use of them to ensure maximum performance

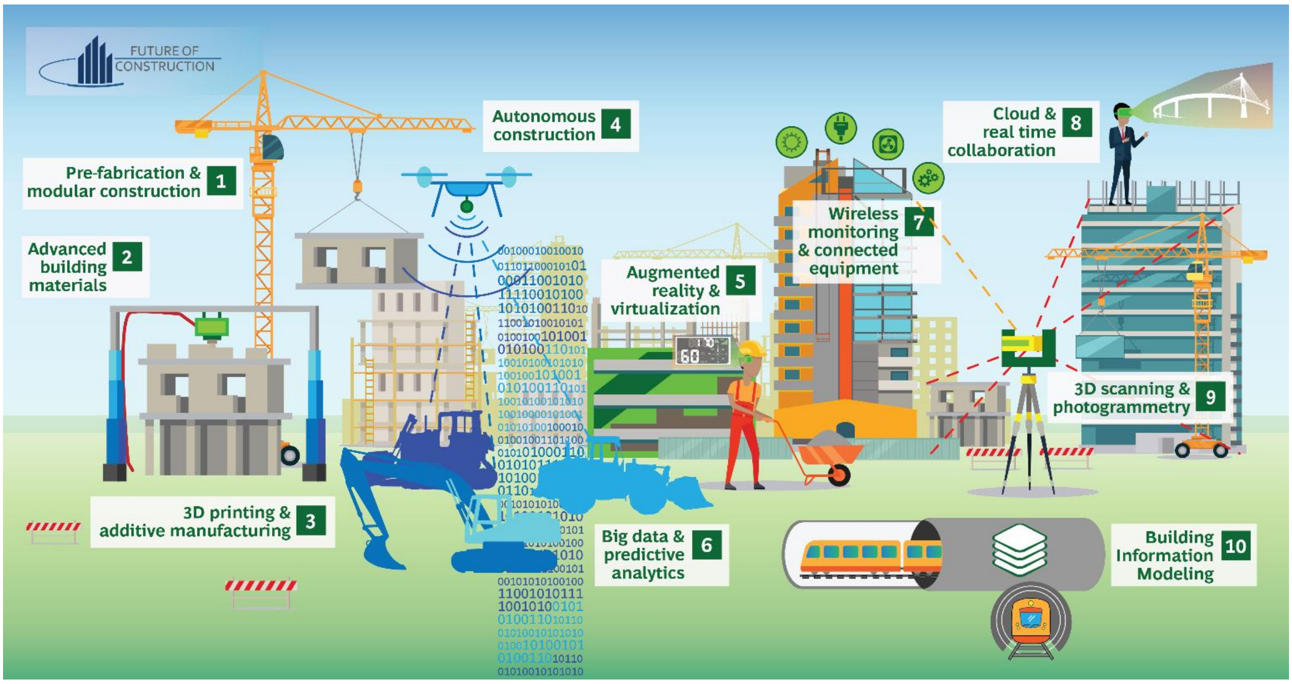
3.2. Complexities

- Optimal planning only for important buildings for which a change of use is not envisaged, even in the long term (e.g. hospitals, gyms, ...); counterproductive choice for small buildings
- Impossible to carry out major interventions and/or major configuration changes, or, if possible, too prohibitively expensive

- High cost of most good quality materials that guarantee high performance for a long time
- Need for coordination between the designers of the various systems and the structure, also with the use of BIM, for the best possible integration and to ensure easy access to all of these and to indicate on the model what is required for maintenance even by figures not directly involved in the design phase

CHARACTERISATION OF BEST PRACTICE H

UNIVOCAL CODE	**BP_H**
NAME	IMPLEMENTATION OF DIGITAL TECHNOLOGIES
OBJECT	Components – Whole building
LIFE CYCLE STAGE	Design – Construction process - Operation and use – Refurbishment – End of life
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Training for designers, software licences, cutting-edge technology



1. CHARACTERISTICS

1.1. DESCRIPTION

Digital technologies can be quite useful in all phases of a building's life, from design to end-of-life: they allow continuous monitoring of the building and its needs, better collaboration between the professionals involved, and overall project optimisation. They are also supportive of many of the other best practices identified, such as DfD, DfA, general tracking of material flows, whether virgin or reused, and more broadly efficiency-oriented design.

1.2. RELEVANCE FOR CIRCULAR BUILDINGS

The use of digital technologies is vital for a life-cycle approach: in particular, it allows the optimisation of the use of materials and resources, both in terms of concrete design and by linking stakeholders in the supply chain, thus acting on logistics and production. It allows access to the building's data at any time, both at the level of materials, monitoring its performance and tracking the interventions to which it is subject, and of energy and water consumption: in this way, circularity, with maximum reuse and/or recycling, is maximised for all resources.

1.3. Innovation aspects

A highly technology-driven approach to building design and management is now recognised as the innovation most needed for the transition to a circular sector: it imposes itself as a solution to the traditional supply chain problems of extreme fragmentation and lack of collaboration. This innovation affects all those involved in the life cycle: first and foremost, designers, who must be trained to use BIM tools to be able to integrate their work with other professionals; construction companies must also adapt, especially with regard to the use of cloud-based site data management tools. This digital transformation is highly central to achieving circularity in the sector: in the coming years, those who are not ready to fill the technology gap are destined to be excluded from the supply chain.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Integration of sensors and home automation in buildings
- Realisation of the Digital Twin of the building in a BIM environment, also thanks to computer vision technologies for the digital reproduction of components
- Use of drones (or Lidar and Laser Scanner) for site and building survey and control
- Support of IoT technologies for real-time data transmission
- Introduction of Machine learning (AI) to predict maintenance and intervention needs
- Use of project management software
- Creation of a cloud environment for sharing useful information for building operations
- Use of GIS technology
- Modelling and 3D printing of components

2.2. Involved stakeholders

- Architects
- Structural designers
- Plant designers
- Construction companies
- Demolition companies
- Other construction companies
- Plant installers/ maintainers
- Window fitters
- Flooring companiess
- Building materials manufacturer
- Manufacturers of plant components

3. Impact

3.1. Benefits

- Possibility of creating a Digital Twin of the building of which one knows in real time the requirements, the quantities of materials present, the operations to be carried out on it and how to intervene, especially in disassembly
- Optimisation of each designer's work, having a single model where everyone can contribute and pay attention to interference, e.g. with regard to installations, avoiding design errors
- Comprehensive information on the building is easily available at any time by those involved
- Ensuring safety and well-being for building users through the inclusion of sensors and automation/domotics systems
- Facilitated identification of opportunities for recovery and recycling of components

3.2. Complexities

- Difficulties in transition to a more digital approach by designers and companies with more ‘traditional’ ways of working
- Higher costs to enable continuous monitoring and to survey the whole building by points and in general for the introduction of digital tools
- Lack of economic incentives for the introduction of digital tools
- Need for active and continuous collaboration of all stakeholders in the different phases of the building's life
- Continuous updating of technologies to avoid obsolescence
- Perception by stakeholders that digital tools can disproportionately replace human labour and lead to unemployment

CHARACTERISATION OF BEST PRACTICE I

UNIVOCAL CODE	**BP_I**
NAME	CREATION OF OR PARTECIPATION TO COLLABORATIVE PLATFORMS / DATABASES
OBJECT	Materials – Components
LIFE CYCLE STAGE	Design – Construction process – End of life
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Availability, Licences

1. CHARACTERISTICS

1.1. DESCRIPTION

Participation and/or the creation of online platforms and databases, where it is possible both to collect information regarding the materials used in different buildings, facilitates decision-making processes and the evaluation of circularity, but also to provide an overview of materials or components that have been discarded from buildings and that could be useful to other designers or construction companies, in order to promote their reuse. Similarly, a participatory approach is also useful to connect the people involved in the construction sector.

1.2. RELEVANCE FOR CIRCULAR BUILDINGS

The shared management of databases, as well as the creation of platforms for secondary markets for re-use and recycling products, acts directly for the circularity of materials. Collaboration has already been said to be central for all optimisation of building layouts and supply chain organisation: for instance, integrated logistics between several manufacturers can minimise the necessary transport and reduce resource consumption.

1.3. INNOVATION ASPECTS

In the collaborative approach between stakeholders, the principle of Rethink is applied to the entire supply chain, reshaping the traditional philosophy in which everyone acts only for his or her own interests: those who are not prepared to put their own gains, even partially, in second place to a circular and shared evolution of the construction process, will in the long run be excluded from it. At the same time, a commitment on the part of companies to research and load materials into these circularity databases is required in order to be able to create ever larger reuse markets that offer a viable and affordable alternative for all contractors, to the detriment of the market for virgin materials.

2. TECHNICAL INFORMATION

Main technical information as given by the literature.

2.1. PRACTICAL APPLICATIONS

- Creation of a database for the building in which the materials used are entered, with their quantities and properties, also with the help of BIM design
- Registration of the companies involved in platforms (e.g. Circularity Platform) for the circularity of materials
- Identification of industries and companies with which to create industrial ecosystems, generating continuous supply chains for products and easy to replicate over time
- Creation of easy-to-navigate and intuitive platforms to facilitate the use of many users
- Use of platforms for temporal and spatial synchronisation of the figures involved in the various processes on the building
- Use of platforms not only for material flows around a project, but also for interchange between different projects
- Initiative of companies and designers in proposing and joining circularity projects

2.2. INVOLVED STAKEHOLDERS

- Architects
- Structural designers
- Plant designers
- Construction companies
- Demolition companies
- Window fitters
- Public administrations

3. Impact

3.1. Benefits

- Circulation in the market of re-use products, keeping track of the origin of each one
- Easier sourcing of reuse and recycling materials without having to have direct contact with individual dismantling companies
- Reduction of waste of materials and components that are not reused because they are not claimed by anyone for a second use
- Creation of an internal market among stakeholders involved in the circularity of materials specifically for construction
- Collaboration between the different stakeholders, especially in the design phase, to know all the needs and precautions to be followed, especially for the circularity of materials (co-design)

3.2. Complexities

- Still limited stakeholder participation in platforms so there are few products in the catalogue
- Need for BIM design or a complete inventory to be aware of the real amount of material involved
- Lower landfill costs compared to the price of reuse materials
- Difficulties for stakeholders to find exactly what they need in databases and platforms, but also problems for small companies to fit into collaborative frameworks with considerably larger companies
- Information and training needed for those who want to approach the use of databases
- Lack of involvement of all levels of stakeholders, including local authorities

CHARACTERISATION OF BEST PRACTICE J

UNIVOCAL CODE	**BP_J**
NAME	DRAFTING AND USE OF MATERIAL PASSPORTS AND CERTIFICATIONS
OBJECT	Materials – Resources – Components
LIFE CYCLE STAGE	Design – Product manufacturing – Construction process - Operation and use – Refurbishment – End of life
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Software availability, Licences, Data availability

1. Characteristics

1.1. Description

In order to favour the choice of materials and products with limited environmental impact, it is advisable that these are accompanied by an environmental certification (e.g. Environmental Product Declarations - EPD) or a document that is able to provide indications as to their origin, production and use (e.g. Material Passport); the latter is fundamental for the circulation of reuse products in order to have knowledge of their provenance and the performance that can be expected.

1.2. Relevance for circular buildings

The use of environmental certifications particularly influences the design phase and the choice of materials: circularity is achieved by choosing materials for which low impacts are certified and whose water and energy consumption is known, thus focusing on the Reduce principle of the circular economy. The certifications themselves assess the entire life cycle of the product, from the extraction of the raw material to the end-of-life phase: in this way, the choice approach is approached in the most conscious manner possible, especially with regard to possible reuse or disposal. The digital passport, similarly, keeps track of the material's journey, acting mainly as a guarantee for those who recognise the environmental benefit of choosing reusable materials over virgin materials.

1.3. Innovation aspects

The main innovation consists in the tracking, assumed in the case of environmental declarations, while actual for the digital passport, of the product's journey and all the impacts and consequences related to it; in the case of PLRs, a constant commitment and much attention by the figures involved in their updating are necessary so that the data are as complete as possible and provide all the necessary information to those who will operate or reuse the same materials. Special data storage software is needed to do this, and operators in the different phases of the life cycle need to know how it works; DPPs can be integrated into BIM models at the same time, so competent professionals are always needed. On the other hand, as far as certification is concerned, innovation must be of particular interest to companies producing construction or plant materials: it is up to them to demand that they produce materials with a reduced environmental impact and certify them, so that contractors who in turn strive for circularity can find materials that meet their requirements; in this way a virtuous circle of circularity-conscious production, design and realisation is created.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Search for materials to be used in the project on databases and platforms for the collection/redemption of Environmental Product Declarations
- Keeping track of the origin and operations carried out on materials or products, also with the use of BIM, in case they are to be reused and this information is needed for the material passport
- Request of EPD certifications from organisations in charge and authorised to draw them up, by manufacturing companies
- Inclusion in material passports, by manufacturers and/or designers, of all useful information for the post-construction phases in order to facilitate those involved in maintenance and disassembly operations
- Referring to declarations when choosing materials, especially to know the expected service life and performance without the need for further testing
- Creation of material databases in a building (building as materials banks)

2.2. Involved stakeholders

- Architects
- Structural designers
- Plant designers
- Construction companies
- Other construction companies
- Plant installers/maintainers
- Window fitters
- Flooring companies
- Building materials manufacturers
- Manufacturers of plant components

3. Impact

3.1. Benefits

- Traceability of materials
- Ability to access the information you need about the product immediately and accurately
- Increased use of reused and recycled materials, with performance declarations to provide assurance to designers and contractors
- Increased use of materials with low environmental impact to the detriment of non-certified virgin materials
- Greater possibility of obtaining sustainability certification for the entire building from the level of individual materials
- Incentives for the manufacture and trade of environmentally certified products

3.2. Complexities

- Lack of precise guidelines for the drafting of Material Passports
- Need for a lot of information to obtain certifications, especially in the case of reusable materials
- Cost of EPD certifications
- Lack of interest on the part of manufacturers in certifying their products if they provide better mechanical performance than competitors
- Need for continuous updating of certificates and material passports whenever an operation or transformation is carried out on them
- EPD can only be drawn up after an LCA, which is not always easy due to the need to know the supply-chain of materials

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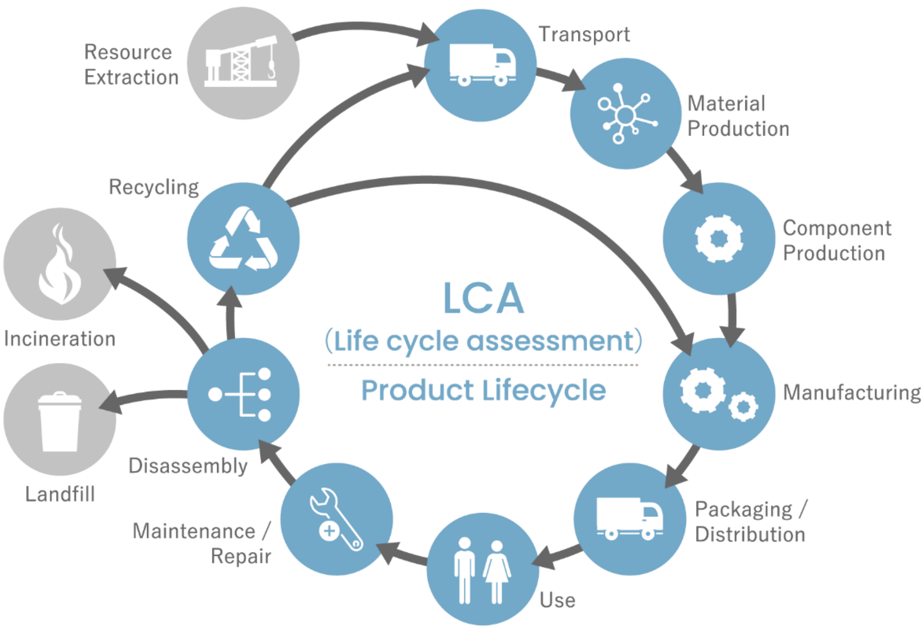
CHARACTERISATION OF BEST PRACTICE K

UNIVOCAL CODE	**BP_K**
NAME	LIFE CYCLE AND LIFE CYCLE COSTING ASSESSMENT
OBJECT	Materials – Resources – Components – Whole building
LIFE CYCLE STAGE	Design – Product manufacturing – Construction process - Operation and use – Refurbishment – End of life
CONDITIONS FOR AVAILABILITY/PREREQUISITE	License, Trained professional, Data availability



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1. Characteristics

1.1. Description

Life Cycle Assessment is a useful tool for monitoring the impact of materials, components and the whole building, mainly in environmental terms, at all stages of the life cycle, from production to end of life. The LCA is used at the same time to make choices between design alternatives, with the support at the same time of the Life Cycle Costing Assessment, which is useful for evaluating the investments, returns and economic benefits that can be derived from different construction interventions.

1.2. Relevance for circular buildings

The LCA is extremely useful for making conscious design choices in terms of environmental impact: by going to consider all phases of the life cycle of the building or one of its components, one is able to use the results of this assessment both to make the best design choices from the point of view of the circularity of resources (according to the principles of Reduce, Reuse and Recycle), and to identify parts of the building or operations on it that undermine, for example, the efficient use of energy or materials; with respect to this last point, the LCA is able to lead to a rethinking of the building or a refurbishment of problematic parts of it.

1.3. Innovation aspects

The innovation of LCA lies not so much in the procedure and the basic idea, which have been recognised for years as valid for assessing the sustainability of products and buildings: the real transformation that needs to take place in the construction sector is its systematic integration into decision-making processes. To achieve this requires the collaboration of all stakeholders: first there must be the commitment of manufacturers to provide information on the impacts generated in the manufacture of building materials; then it is the turn of designers to integrate this same data into the BIM model to observe how the impact of the building changes in relation to design choices and identify the best solution from this point of view. Finally, there must also be the involvement of the bodies in charge of dealing with the end of life of materials: they too are asked to make the best choices for circularity by evaluating different scenarios of reuse, recycling, recovery or disposal. The LCC in turn is an innovative tool that allows, thanks to empirical tools and financial models, to monetise the benefits: it would be opportune that the figures involved in the life cycle assessment of investments be educated on the potential of this tool and implement it, so that choices are made counting also the benefits deriving from circularity choices, which are usually considered as an investment.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Use of software such as OpenLca for the assessment of individual materials or reference to databases such as EcoInvent
- Evaluation of the entire building based on the LCA results of the individual materials or components involved
- Preference for manufacturers who are able to provide EPDs of the products of interest to facilitate the LCA calculation of the entire building
- Realisation of the LCA following the steps provided in ISO 14040/44 after choosing a system boundary suitable for the situation to be analysed
- In the LCC for the evaluation of market opportunities, also consideration of incentives and tax breaks resulting from circularity choices
- Use of the LCA on reuse materials to promote their reuse in other buildings and demonstrate the advantage in comparison with the same virgin materials

2.2. Involved stakeholders

- Architects
- Structural designers
- Plant designers
- Building materials manufacturers
- Manufacturers of plant components
- Certification body audit

3. Impact

3.1. Benefits

- Identification of the most impactful processes or materials and more sustainable alternatives at the earliest design stage
- Verification of compliance of design choices with environmental regulations
- Identification of opportunities for innovation and quantitative demonstration of their potential
- Evaluation and comparison of interventions on existing buildings, with quantification, including monetary quantification, of their benefits
- Increase in the use of innovative and low-impact materials in buildings compared to traditional materials that appear worse on the LCA
- Quantification of the actual benefit linked to circularity choices and best practices
- Makes it possible to compare possible end-of-life scenarios for the building

3.2. Complexities

- Complexity in dealing with entire buildings due to the large number of different materials and components involved
- Impossibility very often to extend already made calculations to several buildings
- Lack of complete database coverage of all production processes and especially the processing of demolition materials
- Limitation of the LCA in assessing easily quantifiable impacts, not allowing for complete circularity indices
- Need to adapt the scenarios already present in the calculations to the real situation and possibility of underestimates resulting from assumptions and simplifications
- Need to rely on empirical tools for monetising impacts

CHARACTERISATION OF BEST PRACTICE L

UNIVOCAL CODE	**BP_L**
NAME	DESIGN FOR ENERGY EFFICIENCY
OBJECT	Materials – Resources – Components – Whole building
LIFE CYCLE STAGE	Design – Product manufacturing – Construction process - Operation and use – Refurbishment
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Software licences, training for designers, products availability, Regulations compliance

1. Characteristics

1.1. Description

In order to limit the consumption of energy sources, particularly fossil fuels, it is advisable to design new buildings, or to intervene in the redevelopment of existing buildings, operating from the perspective of energy efficiency: a design of this type envisages obtaining an envelope capable of minimising dispersion, always respecting the regulatory limits in force, and of exploiting free contributions and passive mechanisms; at the same time, the systems are designed to have high efficiencies, without wasting energy when not necessary and limiting losses due to malfunctions.

1.2. Relevance for circular buildings

The design for energy efficiency is based on the principles of the circular economy Reduce and Rethink: in fact, the building is planned to minimise the demand for thermal energy, both thanks to choices concerning the configuration of the building, such as its orientation, and the materials that are chosen to store thermal energy and exploit free inputs. The correct behaviour of the building's user is also part of the reduce perspective: this must be suitably educated for energy saving and can be helped by home automation systems that guarantee maximum efficiency and, at the same time, thermo-hygrometric wellbeing inside the building. A reduction in energy consumption makes it possible to reduce the use of energy sources, nowadays mainly covered by fossil fuels, and consequently the emissions into the atmosphere, decreasing the environmental impact. In addition, the use of heat recovery and controlled mechanical ventilation systems allow for the recycling and reuse of heat once produced.

1.3. Innovation aspects

As energy efficiency regulations are constantly evolving, and performance requirements are becoming more and more binding, innovation in the approach must lie in adopting solutions in advance: in the case of new buildings, it is not enough to simply comply with regulatory constraints, such as for envelope transmittances, but to aim for the best possible environmental performance, despite the necessary investment. In the case of existing buildings, interventions must be timely, as any delay in energy upgrading entails an impact that cannot be compensated for later. As far as technological innovations are concerned, manufacturers must engage in the development of new materials and new plant technologies that improve the energy performance of buildings, while those who choose building components must consider the contribution they can make. Suppliers of plant components must innovate in the integration of sensors and probes to monitor the efficiency of the systems: in this way they can intervene and extend their useful life as much as possible.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Use of materials with reduced embodied energy (including reused materials)
- Adequate wall insulation, with overall transmittances of opaque closures lower than those required by regulations
- Windows and doors with at least double chamber and thermal break frames and shading systems
- Building orientation and configuration to minimise dispersion (e.g. compact configurations)
- Attention also to passive heating solutions (e.g. materials with high thermal inertia)
- Installation of probes and detectors of internal conditions for the automatic control of systems, also with the contribution of home automation, and careful maintenance
- Optimisation of construction and demolition processes, especially in terms of means
- Installation of state-of-the-art generators and heat recovery units
- Identification and meticulous elimination of thermal bridges
- Thermodynamic modelling of the building, preferably on an hourly basis

2.2. Involved stakeholders

- Architects
- Structural designers
- Plant designers
- Construction companies
- Plant installers/ maintainers
- Window fitters
- Building materials manufacturers
- Manufacturers of plant components

3. Impact

3.1. Benefits

- Reduced building running costs
- Better control over indoor comfort for the user
- Reduction of CO2 emissions and environmental impacts in general
- Possibility of achieving zero energy buildings (NZEB or ZEB buildings) by adopting such solutions in combination with the introduction of renewable energy sources and on-site production
- Ability to constantly monitor consumption through the use of sensors and plant control bodies
- Opportunity to replace old, inefficient plants, very often burning fossil fuels, with new, less impactful and higher performance plants

3.2. Complexities

- High costs of the latest generators and the most thermally efficient materials
- Higher impact of insulation materials compared to others and numerous difficulties in their recycling and/or reuse
- Continuous evolution of building energy performance regulations, resulting in the need to go beyond the required limits and thus the risk that new interventions will be necessary in the short future
- Need for elaboration, accompanying redevelopment projects, of solutions for the management of waste arising from the decommissioning of, for example, old windows and doors
- Indication in reference frameworks of design optimisation criteria limited to the operational phase of the building only

CHARACTERISATION OF BEST PRACTICE M

UNIVOCAL CODE	BP_M
NAME	TRANSITION TO RENEWABLE ENERGY SOURCES
OBJECT	Materials – Resources – Components – Whole building
LIFE CYCLE STAGE	Design – Product manufacturing - Operation and use – Refurbishment – End of life
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Training for designers, Products availability

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1. Characteristics

1.1. Description

Even if the energy needs of buildings or individual materials are reduced, it is necessary that renewable and clean energy sources are used to meet them, so that operations such as the combustion of a fossil source, the extraction, processing and transport of which are among the greatest sources of environmental impact, especially on the air, are not necessary. This is also accompanied by the need to have sources that are non-depletable and that allow the energy to be produced directly at the site of consequent use, with ad hoc plants.

1.2. Relevance for circular buildings

The installation of on-site renewable energy production systems, both on existing and new buildings, allows for maximum energy circularity, especially with a view to self-production and self-consumption: by generating energy and storing it to draw on when needed, one is able to avoid wasting what is produced and reduce the energy demand from national lines, which mainly use fossil fuels for production. The use of renewable sources in the production of building materials also reduces the associated carbon footprint and thus makes them more circular. Renewable productions are particularly important for achieving energy circularity in existing buildings, as they make it possible to respond to the surplus of energy demand linked to the low performance of their envelopes.

1.3. Innovation aspects

The integration of renewable energy systems on buildings has been a key topic for environmental sustainability for several years now: innovation for circularity must lie in expanding the scale of application of these systems. More and more technological solutions are being proposed, for example, by solar panel manufacturers: in order for their market not to stabilise, it is necessary to focus on innovative solutions, such as customised panels that can be integrated into any building component, from roofing to walls and window frames; the manufacturers' main commitment must be towards producing panels with local materials, which is impossible today as the market is still dominated by the logic of profit that aims to buy cheap materials in Asian countries: there must therefore be initiatives, including public initiatives and with funding or incentives, that push for the creation of European markets, where costs and emissions related to the transport of materials would be lower.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Installation of photovoltaic panels, with correct orientation, and other plant engineering components necessary for the exploitation of electrical energy, as well as for transferring unused excess to the grid in the absence of batteries
- Installation of thermal solar panels on roofs for the production of DHW or for pre-heating water in heating systems
- Replacing fossil fuel boilers with (renewable) biomass boilers or heat pumps that make better use of electricity production
- Participation in community energy, district heating and district production projects to utilise renewable energy produced in large plants
- Adoption of plant solutions based on geothermal heat production, or electricity from wind and hydro power
- Plant and renewable source choices according to building needs

2.2. Involved stakeholders

- Plant designers
- Plant installers/ maintainers
- Manufacturers of plant components
- Public administrations

3. Impact

3.1. Benefits

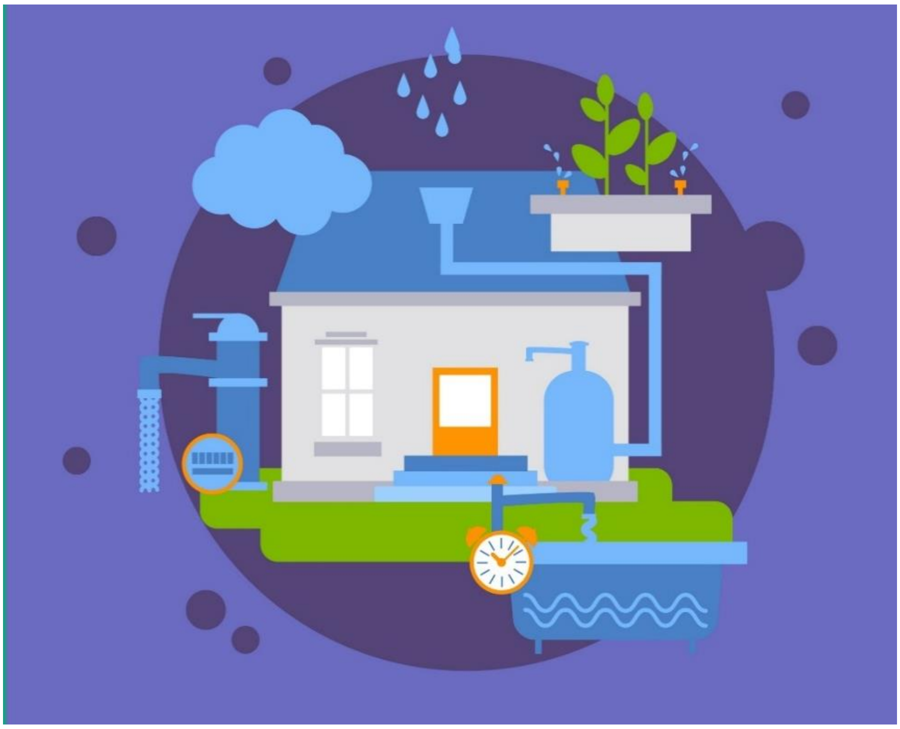
- Possibility of accessing numerous incentives at national or regional level to facilitate this transition to green energy
- Significant economic savings on consumption, with even some profit in the case of electricity sales, once the payback period has elapsed
- Limitation in the production of CO2 and other polluting particles related to fossil combustion
- Possibility of integrating installations from renewable sources even later than the construction of the building, depending on the needs identified
- Different options of choice with respect to the renewable energy source depending on needs and the most exploitable resources
- Integration into most existing buildings

3.2. Complexities

- Production of photovoltaic panels concentrated in Asian countries for which transport is long, expensive and polluting
- Batteries used for electricity storage are highly polluting, non-reusable and have a limited service life, as do most components of photovoltaic systems
- Need for design considerations depending on building configuration
- Difficult integration of renewables in historic buildings due to constraints
- Considerable waste production due to extensive replacement of existing installations
- Large, expensive and space-consuming installations are required for large buildings
- Need for maintenance and frequent replacement of components
- Production is not constant, requiring grid connections, other back-up generators or storage systems

CHARACTERISATION OF BEST PRACTICE N

UNIVOCAL CODE	**BP_N**
NAME	WATER SAVING AND MANAGEMENT
OBJECT	Materials – Resources – Whole building
LIFE CYCLE STAGE	Design – Product manufacturing – Construction process - Operation and use – End of life
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Regulation compliance, Products availability



1. Characteristics

1.1. Description

Like energy, water is a resource that must be used sparingly and without waste, starting from the production of materials, through the construction phases, to the actual use of the building. This best practice includes solutions for water use efficiency as well as those aimed at maximising the reuse of rainwater and ensuring the hydraulic invariance of interventions in the built environment.

1.2. Relevance for circular buildings

The circularity of water is not explicitly included in any of the other best practices and, indeed, is very often not given the necessary importance. The practices indicated here allow for the implementation of the principles of circularity of reduce, thanks to the optimised use of the resource, but also of reuse/recycle, whether it is a question of using rainwater for irrigation, for example, or of inserting devices for the treatment of waste water for reuse. By operating in this way, and educating the building user to save water, we are able to limit the supply from the local water network as much as possible: very large amounts of energy are required to operate the latter's systems, from which derives an equally large impact, which, by adopting these small solutions at the building level, we can reduce.

1.3. Innovation aspects

The main innovation for this practice lies in giving attention to the least considered resource within the building and its production chain: first and foremost, the producer of the materials must limit their use and waste in the processes; the contractor, consequently, must make a choice of materials also based on the minimum embodied water, and in addition must plan the site and construction so that on-site consumption is as low as possible. As far as the designer is concerned, his role is more fundamental than ever, especially to ensure the hydraulic invariance of the project and to limit the hydrogeological consequences of the building, especially in this context of climate change: the integration of collection tanks and green roofs can partly contribute to mitigate the problem. As far as the maintenance phase is concerned, the introduction of devices to identify leaks and malfunctions is in turn an extremely useful innovation for water consumption efficiency.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Minimisation of impermeable pavements, in favour of permeable soils
- Construction of rainwater harvesting cisterns, to be used for non-sanitary purposes such as irrigation
- Installation of water-saving devices, such as flow regulators for taps or drip-catchers
- Systematic checks for leaks
- Reducing the use of water for decorative purposes, unless full recovery is guaranteed
- Inclusion of grey water treatment facilities
- Use of products that in themselves are made with reduced embodied water
- Education of users on the best way to manage water use
- Introduction of solutions for the recirculation of drinking water in order to maintain its quality and avoid the proliferation of bacteria

2.2. Involved stakeholders

- Structural designers
- Plant designers
- Plant installers/ maintainers
- Manufacturers of plant components

3. Impact

3.1. Benefits

- By limiting domestic water consumption, savings, also monetary, on thermal energy production and consequent reduction also of CO2 emissions in the case of fossil fuel generation
- Monetary savings on water consumption
- Minimisation of wasteful use of potable water for less noble purposes such as irrigation
- Reduction of stormwater runoff problems in the city sewer system by adopting hydraulic invariance solutions

3.2. Complexities

- Impossibility of building underground reservoirs or reservoirs of sufficient size to ensure coverage of needs even during periods of low rainfall
- High costs to keep the entire hydraulic system in perfect working order
- Little general interest in water resources, considered less important than energy

- Need, for large complexes, for car parks and paved areas, which, if not impermeable, do not allow for hydraulic invariance
- Lack to date of a global trend in the systematic inclusion of water-saving devices in products available on the market

CHARACTERISATION OF BEST PRACTICE O

UNIVOCAL CODE	**BP_O**
NAME	RELIANCE ON BUILDING CERTIFICATIONS AND CIRCULARITY INDICATORS
OBJECT	Materials – Resources - Whole building
LIFE CYCLE STAGE	Design – Product manufacturing – Construction process - Operation and use – Refurbishment – End of life
CONDITIONS FOR AVAILABILITY/PREREQUISITE	Entrustment to certification body, Data availability

1. Characteristics

1.1. Description

These are indicators or performance levels that quantify the building's compliance with environmental, social and economic standards; in the case of sustainability certification, these provide an indication of the building's primarily environmental impact, particularly in its use phase. The addition of circularity indices serves to focus attention on all phases of the building's life cycle and their impacts, particularly end-of-life practices.

1.2. Relevance for circular buildings

Relying on certification bodies to quantify the sustainability and circularity of the building makes it possible, as in the case of LCA, on which most certification methods are based, to identify the phases and procedures of the life cycle that can be optimised to reduce the consumption of materials and resources, especially in the building's use phase. Furthermore, these certifications are important because they are also able to assess the effects that circular choices have on other spheres of sustainability, and in particular on the social sphere: in this way, tangible demonstrations are obtained of the benefits in terms of the psycho-physical well-being of the user of these certified circular buildings.

1.3. Innovation aspects

Traditionally, these certifications were only focused on the sustainability of buildings, whereas it is now in the interest of the bodies themselves to integrate indicators into their evaluation systems that are able to give a true quantification of circularity. Their usefulness in the transition to a greener construction sector also lies in having provided design frameworks that designers can faithfully follow, even if they are not fully versed in circularity, in order to approach this paradigm in an easy manner. The change most needed now is the extension of interest in these certifications on the part of component manufacturers, designers and construction companies, in order to create a common and participatory momentum, creating an emulation effect, especially on the scale of small buildings and the residential sector.

2. Technical information

Main technical information as given by the literature.

2.1. Practical applications

- Obtaining certifications such as BREEAM, LEED, WELL that quantify the sustainability of the building
- Calculation of indices such as Material Circularity Indicator (MCI) or other indicators in the literature (e.g. Gonzales Method)
- Adherence to the guidelines provided on the websites of the main rating systems to ensure that all material selection and construction procedures are carried out in a manner consistent with what is required
- Use of materials with environmental and EPD certifications
- General compliance with identified best practices
- Adherence to guidelines such as Level(s)
- Use of techniques such as Material Flow Analysis to track material flows for the calculation of other indicators

2.2. Involved stakeholders

- Architects
- Structural designers
- Plant designers
- Plant installers/ maintainers
- Manufacturers of plant components
- Certification body audit

3. Impact

3.1. Benefits

- Access to economic incentives calibrated to the degree of sustainability
- Improved building performance in environmental terms
- Reduced building running costs
- Improved indoor well-being conditions for users
- Increase in the value of buildings with certification
- Quantification through some circularity indicators of the economic return, not only counting actual monetary savings, but also those related to impact reduction and gains from positive impacts
- Emulation effect resulting from the increasing number of certified buildings in the design of new buildings and intervention in existing ones

3.2. Complexities

- Identification of the most representative circularity indices

- Quantification of quantities of materials in existing buildings needed for calculation of indicators
- Problematic quantification of user well-being and the most subjective circularity indicators
- Impossibility to obtain completely reliable and realistic results due to numerous assumptions and scenario simulations
- Need for very often more costly design precautions and choices in order to achieve certifications
- Lack of a definitive framework for assessing circularity, instead of only sustainability

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