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TITLE:

Drivers and barriers towards circular economy in the building sector: stakeholder interviews and analysis of five European countries policies and practices

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ABSTRACT

Circular economy has become central in the European policy arena, and the Member States have promoted a number of initiatives and programs to shift from their traditional linear economy towards a circular economy. This is particularly relevant for the construction sector, which is the highest producer of waste and one of the main causes of resources consumption. The paper objective is to analyse the present level of application of circularity strategies, identifying the related barriers and drivers, through interviews with building stakeholders across five European countries, Belgium (Flanders), Netherlands, United Kingdom, Denmark, and Italy. The analysis focuses on the building level and assesses the level of application in current policies and practices of circular strategies in three key field: resource and waste management, design for reversible building, and business for the networking of operators in the construction value chain. The results highlight the different and fragmented circular strategies currently applied in the analysed countries, highlighting the need for more effective and coordinated actions and policies promoted by European Commission. In particular, the current legislative framework promotes the waste management strategies, focusing more on recycling practices than on reuse or resource management. The design strategies for reversible building are generally in private initiatives, driven by market competitions, rather than by public incentives. The application of circular business models and the creation of circular networks among the operators of the value chain is still lacking. Furthermore, the use of life-cycle tools to assess the environmental effectiveness (sustainability) of circular strategies is rarely applied. The recommendations that emerged from the comparison of the current applications of circular economy strategies across the countries analysed and demanded by key players in the construction sector interviewed, include the need for greater international coordination in terms of policy, practices and enabling tools (digital data, platforms, traceability). Improvements in both the legislative framework and practices are needed. Future development of research regards, in particular, the fields of digital supporting tools and environmental assessment (LCA), circular relationships and business models and the definition/training of new expertise related to enabling aspects.

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Keywords: circular economy policies, resource efficiency, circular buildings, business models, sustainability assessment

1. Introduction

Circular economy (CE), opposed to the current linear economic model, is a pathway to achieve an economic system based on the preservation of natural resources and the avoidance of waste, through for example closed loop strategies, by-product exchange, products reuse, and materials recycling (UNEP, 2006; EMF, 2015; EEA, 2016). In 2019, the European Commission introduced the European Green Deal (European Commission, 2019), which re-launched the CE agenda promoted by the European Commission since 2014 (European Commission, 2014; European Commission, 2015).

The construction sector has been identified as a 'priority area' for this transition, not only because it is fundamental in the economic system providing about 9% of the EU's GDP (EC European Commission, 2018a), but also because it produces the highest quantity of waste in the EU (Eurostat, 2016), generating about 850 million tonnes of construction and demolition waste (CDW) per year (S ez and Osmani, 2019). In addition, it accounts for about 50% of all extracted materials (European Commission, 2020), which is expected to increase in the future (Fishman et al., 2016), causing relevant environmental impacts (Lavagna et al., 2018; Onat and Kucukvar, 2020).

Scientific literature in the CE field related to the building sector has increased in recent years, but most of the studies regard the waste management (Hossain et al., 2020; Munaro et al., 2020; Norouzi et al., 2021), proposing recycling as the most feasible strategy (Schöggl et al., 2020; Pan et al., 2020) and focusing on the material level. Moreover, CE is investigated through a quantitative approach by calculating the stocks of materials for the optimization of the waste flows management at the district level (Fernandez, 2007; Koutamanisa et al., 2018; Mao et al., 2020; Arora et al., 2020). According to Pomponi et al. (2017), there is the risk of ignoring the potentials of individual buildings for CE transition, since the building level is less discussed in literature.

Therefore, this paper, through a literature review (considering scientific literature, roadmaps, position papers), identifies the strategies and related enabling tools for applying CE at building level, grouping them in three key field of application: 1) *resource and waste management*, 2) *design for reversible building*, 3) *business and stakeholders networking*.

1) The first group of strategies deals with the improvements in management of inflow and outflow materials from the building process, through a better waste identification and quality processing which facilitate solutions to avoid the generation of waste, during the construction phase and the end of life (Osmani M. and Villoria-Sàez P., 2019; Silva et al., 2019). Studies (Gorgolewski, 2019; Lopez Ruiz et al., 2020; Condotta et al. 2021) have proposed diverting waste from landfills by reusing materials or components, despite reuse is identified as the best practice of building materials management according to the Framework Directive 2008/98/EC and the European Protocols enacted within European Circular Economy Package (European
2) Commission, 2016; European Commission, 2018b). Other scientific contributions deal with traceability systems of materials and information, through digital technologies that trace the geometric and mechanical characteristics of the components, the location, the residual value of the materials, the age, and the expected life cycle, to allow knowledge of potential components to be reused in a new project (Minunno et al., 2018). Pre-demolition audits, carried out by an expert, are identified as useful tools for determining the compositions of materials and improving the reliability of the calculations of the materials to be traced, as well as allowing the evaluation of alternative demolition/recovery options (Rašković, 2020).

3) The second group of strategies concerns the change in design and construction process to obtain flexible, adaptable and disassemblable buildings, conceived as “material banks” (Eberhardt et al.,2019; De los Rios et al., 2017; Lavagna et al. 2020; Durmisevic, 2019; Buildings As Material Banks (BAMB) EU Horizon 2020 project). Construction technologies for a reversible building regard the use of prefabricated and modular elements, dry technologies, mechanical connections, off-site constructions, and high durability products, to allow easy construction reversibility and enable the reuse of spaces and components, extending their useful life. In this field, Building Information Modeling (BIM) is identified as an enabling tool for monitoring the use of resources during the whole life cycle, sharing information between operators and simulating the reuse potential of the materials in different types of designs early in the project (Akanbi et al., 2018; Akanbi et al., 2019; Charef et al., 2021; Campioli et al. 2018). In addition, the use of BIM software facilitates the use of ‘material passports’, which are important tools to maintain knowledge of all building materials in the long term and preserving their (economic) value (Luscuere, 2017; EPEA, 2017; Munaro et al., 2019). Through a shared material passport system, it is also possible to know the quantity and the location of materials stocked in the urban mining. Furthermore, the sustainable building certification systems (Green Building Rating system) are also identified as a tool for promoting design for circularity; in fact, sustainability certification influences many intervention choices and design, construction and demolition activities (Giorgi et al., 2019).
4) The third group of strategies deals with new effective service-oriented business models (e.g. Product Service Systems, Pay-per-Use, Buy-back-based, Leasing or Rental/Ownership-based) to change ownership and responsibility of products, and improve products’ maintenance and reuse during the use phase, and recycling in the end-of-life phase (Bocken et al., 2016; Wang et al., 2019). This emphasises the importance of new organizational and management structures, stakeholder networks and green deals created along the value chain of the construction sector. Consequently, developing digital collaboration tools to encourage new business models and collaborative and dynamics networks based on materials circularity is fundamental (Hossain et al., 2020; Geissdoerfer at al., 2018; Leising et al., 2018; Dalla Valle et al., 2021). Hence, tools for boosting the implementation of a circular economy in the building sector have been developed in recent years. In particular, there are examples of platforms for exchanging materials and developing collaboration for ‘circularity’ of materials in the end of product life (Baiani et al., 2018) and platforms for pursuing collaborative process and networks among different actors (Lööf, 2019; Konietzko et al., 2019; Talamo et al., 2020).

In literature several studies investigate the link between circularity and sustainability by applying tools such as Life Cycle Assessment (LCA), Life Cycle Costing (LCC) to assess the level of environmental and economic sustainability of CE strategies (Eberhardt et al., 2019a; Romnee et al., 2019; Nasir et al., 2017; Brambilla et al., 2019; Buyle et al. 2019). Indeed, circular strategies, like reuse and recycling, are activities that could generate negative environmental externalities (Di Maria et. al, 2018; Mousavi et al 2016). In fact, the promotion of reuse and recycling, without impact assessment, can encourage, for example, waste trades without distance limits and reduction of products’ durability (Lavagna et al., 2020a).
All the strategies and tools mentioned so far are widely discussed in the literature, but still little applied in practice, if not in a few experimental cases. It is therefore important to understand what are the drivers and the barriers to their application. Part of studies in the literature investigate on drivers and barriers towards CE in different perspectives, such as organizations’ perspectives (Masi et al., 2018, Liu and Bai, 2014), small and medium enterprises’ perspectives (Rizos et al., 2016; Tura et al., 2019), industrial perspective (Oghazi

and Mostaghel, 2018), and different analysis based on literature reviews (de Jesus and Mendonça, 2018; Kirchherr et al. 2018). However, there are still few studies on the identification of CE barriers and drivers considering the building sector (Billal et al. 2020).

Mahpour (2018), Liu et al. (2021) and Adams et al. (2017) analysed barriers and drivers within the management of CDW, identifying mainly the lack of market mechanisms to promote materials recovery and an ineffective process chain for recovering. Condotta et al. (2021) analysed inconsistencies and possible improvements to reuse strategy and show how time frames, costs, performance assessment, and end users perception are the more involved criticalities in the enactment of reuse processes in architecture. Kanters (2020) analysed barriers and drivers within circular building design, identifying as main barriers the conservativeness of the building industry, the lack of political priority and the dependency throughout the building industry, while as main driver a supportive client with a well-defined assignment. Similarly, Cruz Rios et al. (2021) understood the barriers to circular building design in the United States, in this case identifying more educational and cultural barriers, rather than regulatory and technological barriers as well as in EU countries.

Hart et al. (2019) found the obstacles and drivers of CE in UK construction sector, asserting that technological and regulatory developments alone will not be enough to overcome barriers, and a change in business models and in stakeholders' behaviors are needed.

Analysing the literature, it is evident that most of scientific studies on CE barriers and drivers in construction sector regard a single life cycle stage of building, even if the CE concept should concern all life cycle stages of building. Moreover, most of scientific studies investigate only one CE strategy (e.g. Design for Disassembly; material reuse) by observing it alone, without showing the relation of different strategies. Furthermore, generally, most studies consider a unique stakeholder perspective (e.g. designers), without investigate the different point of views of building value chain actors. Most of the studies consider the application of CE in the construction sector within a single country, without a comparison between different geographical contexts.

Furthermore, the state of the art of the practices is not evident in the literature. Only Bilal et al. (2020) assessed, using an online questionnaire, that the overall level of implementation of the EC in the construction sector in the EU is 58%; however this study did not highlight the specific practices introduced to move to the CE from different countries.

According to Hossain (2020), in the literature few studies considered multiple aspects of the CE together, combining political, practices and environmental dimension, and mostly of them are at the material level, rather than considering the whole building. A comprehensive approach, extended to the entire life cycle of buildings towards the effective adoption of the CE principle, considering many aspects, is almost absent (Hossain et al., 2020).

Starting from this gap, this paper analyses multiple CE strategies across building life cycle, emerged from the literature (resource and waste management, design for reversible building, circular business models), with the objective to identify their current application in policies and practices and their link with environmental sustainability assessment, picking out the best-initiatives defined by each country to overcome the obstacles, the related main drivers and barriers from the perspectives of multi-actors of building value chain, across different geographic contexts.

Consequently, the paper aims to answer the questions:

- To what extent are the CE strategies at building level, dealt with in the literature, really applied in European countries? What impact do they have on policies? What impact do they have on operational practices?
- What are the enabling factors and obstacles to be found in the dimensions of policy and practice?
- To what extent is the environmental sustainability assessment really applied for CE activation? To what extent are policy and practice promoting sustainability assessment of circular practices?

The findings show the current level of application and environmental assessment of CE strategies at building level both in the legislative framework and in practices, across five European countries. A cross-comparison highlights the similarity or the difference of barriers and drivers by geographical area, the best practices potentially transferable between different national contexts, the recommendation towards CE useful to policy-makers and stakeholders.

The study reported in this paper provides a scientific contribution, because of the following novelties:

- the analysed CE strategies and related supporting tools (resource and waste management, design for reversible building, circular business models) concern the entire life cycle of buildings and not only a single phase;
- the analysis of CE application at building level considers multiple dimensions: legislative and economic framework, public/private initiative and practices, operators' relationships, supporting digital technologies, life cycle sustainability assessment;
- the adoption of a field research approach to collecting data, which entails a dialogue with all different stakeholders involving throughout the construction value chain, taking into account their needs and their experience;
- the conduction of a parallel analysis within five European countries providing a cross-comparison analysis of these different geographical realities.

2. Methodology

2.1. Sample selection and stakeholder interviews

The research adopted a qualitative and on-field approach via semi-structured interviews and dialogue with different stakeholders and operators of the building value chain, to investigate current policies and practices of circular economy at building level and associated initiatives, barriers and drivers (Fig.1).

The investigation by semi-structured interviews were held across five different European countries: Belgium (Flanders) (BE), Netherlands (NL), United Kingdom (UK), Denmark (DK), and Italy (IT), which were selected considering the following aspects. These countries constituted an interesting field of research because they demonstrate a national interest in the CE, and the diversity of the context allows the authors to investigate a variety of dynamics and impacts in the political and practical fields.

In fact, according to statistics, all five countries have already achieved the Waste Framework Directive 2008/98/CE target, i.e., 70% recovery for construction and demolition waste (CDW) by 2020, considering that all five countries have a similar composition of CDW (in which the aggregates represent 80-90% of total waste), but different social background and political systems. Specifically, the percentages of recycling and other recovery of CDW (soil excluded) related to year 2012 (Resource Efficient Use of Mixed Waste, Member State factsheet) declared by each country are: 89% in Flanders (Belgium)[1], 98% in Netherlands, 86,5% in UK, 86% in Denmark, and 76% in Italy. Furthermore, all these countries already have policy programmes or roadmaps towards circular economy in the construction sector, namely: '*Material conscious build in cycles*' in Belgium (OVAM, 2014); *'A circular economy in the Netherlands by 2050*' (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2016); the *'Strategy for circular economy*' (Miljø- og Fødevareministeriet og Erhvervsministeriet, 2018) in Denmark; CE national policies (Green Public Procurement criteria) and regional roadmaps in Italy, e.g., the Lombardy Roadmap for Research and Innovation on Circular Economy (Regione Lombardia, 2020); and the regional programmes in UK[2].

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[1] *Related to 2007 and declared in: European Commission DG ENV, Bio Intelligent Service, Final Report Task 2, 2011*

[2] England: "Resources and waste strategy: at a glance", 2018; Wales: "Wales the future Generations act", 2015, and "Waste Prevention Programme", 2013; Scotland: "Circular economy strategy Scotland", 2016.

Figure 1: Data collection process

The semi-structured interviews were preceded by a literature review (desk research), presented in the introduction, which aid to identify the main CE strategies and related tools applicable at building level (grouped in three key field of application) and the importance of sustainability assessment to evaluate the effectiveness of CE. This literature review also developed a foundational understanding regarding current CE barriers and drivers.

On the basis of this initial literature review, the authors decided the framework of the interviews: to investigate the level of application of CE in the construction sector, for each key field, three strategies are identified (Table 1). Consequently, the semi-structured interviews were designed and carried out to investigate all these nine strategies, on which the results of the interviews will be articulated in the next section "result and discussion".

Table 1: The strategies to apply circular economy at building level in the three key field of application

resource/waste management (cfr. Section 3.1)	- Avoidance of resources consumption and materials landfilling - Reuse of building materials beyond recycling - Traceability system for materials/waste
design for reversible building (cfr. Section 3.2)	- Constructive technologies for a reversible building - Use of BIM and materials passport - Use of sustainability certification to orient design
business and stakeholders' networking (cfr. Section 3.3)	- Service-oriented business model for building products - Networking among operators for circular business - Green deal among stakeholders for circular discussion

In order to bring out the different dimensions, with regard to policies, practices and sustainability, of the CE strategies in the construction sector, the open-ended questions were divided into five main themes:

- the current national or regional policies which represent an obstacle, due to non-flexible or outdated regulations, or which represent an advance, through righteous obligations or incentives;
- the public/private initiatives which can represent a bottom-up trigger for competitions among operators towards circular practices;

- the operators' relationships to establish particular networks to activate profitable and sustainable dynamics for circularity;
- the supporting digital technologies, like digital platforms for material/information exchanges, or supporting software for design;
- the life cycle tools, like LCA and LCC, to assess the sustainability of the circular strategies with a life cycle approach.

For each topic, authors defined questions (Table 2), destined for the most involved, and therefore more responsible, stakeholders. The questions introduced a dialogue with each informant from each European country analysed. Each interview-meeting was carried out with one stakeholder at a time, in person or via Skype, and lasted a minimum of 1 hour and a maximum of 2 hours.

Table2 Overview of the questions used in the interview

THEME	QUESTIONS	STAKEHOLDER
Legislative and economic framework	Which current policies promote the circular economy in your country?	policy makers
	What are the economic and legislative barriers to buildings' component reuse and material recycling?	policy makers, investors, banks, construction companies, designers, demolisherss, waste managers, producers
	In your country, are there incentives for the reuse of buildings components and/or materials recycling?	policy makers, investors, banks, construction companies, designers, demolisherss, waste managers, producers
	Is there a market demand for reused/recycled materials?	waste managers, demolisherss
	In your country, are there incentives to build a reversible building?	policy makers, investors, banks, construction companies, designerss
	In your country, are there economic and legislative barriers to build a reversible building?	policy makers, investors, banks, construction companies, designerss
	Which policies can promote new business models such as providing services rather than selling products?	policy makerss
	Are there incentives (to producers or clients) for promoting new business models?	designerss
	What are the financial barriers to activating circular business models (e.g., paying for services rather than paying for products or leasing)?	banks
Public/private initiatives	Are there specific public procurement requirements regarding the use of resourced, recycled content, waste management or reversible construction?	policy makerss, investors, banks, construction companies, designers, demolishers, waste managers, producer
	In your country, are there public/private initiatives about the traceability of materials and waste?	policy makers, demolishers, waste managers, construction companies, designers
	In your country, are there public/private initiatives in favour of reversible building?	policy makers, investors, construction companies, designers, demolishers, producer
	Are there public / private initiatives in your country that promote circular business models?	policy makers, investors, construction companies, designers, demolishers, waste managers, producer
	How attractive is a reversible building in your business?	investors, banks, designers, producer
	Is your company interested in new networks to activate new business models (e.g., pay for services rather than pay for products or leasing)?	investors, business expert, construction companies, demolishers, producer
Operator's relationships	Is there a shared awareness, among operators, about the economic value of materials input and output from the building site?	policy makers, investors, banks, construction companies, designers, demolishers, waste managers, producer
	Does the designers know the material flows output from the building site? Which types of assessment are used?	designers, demolishers
	What are the relationship difficulties during a reversible circular building process?	designers, construction companies
	Does construction companies know the destiny of construction waste (which parts go to landfill and which parts go to recycling/reuse)?	construction companies, demolition company, waste management

	Are there specific operators who control the material/waste flows during the building process?	construction companies, designers
	What kind of relationship do you have with the waste producer? How does the exchange of secondary raw materials take place?	producer
Supporting digital technologies	Are there any digital technologies or tools useful for measuring and monitoring the use of resources during construction and demolition phases (or for other phases of the life cycle of the building)?	policy makers, investors, banks, construction companies, designers, demolishers, waste managers, producer
	Are there exchange platforms for supporting element reuse and materials recycling? How much are these platforms used?	business expert, designers, construction companies, demolishers, producer
	Which are the tools or incentives that influence choices among alternatives about renovation (e.g., maintenance or demolition)?	investors, designers
Life cycle sustainability assessment	Are life cycle environmental assessments promoted by the policies?	policy makers
	Are life cycle environmental assessments tools used during the building process? In which phases?	investors, designers, construction companies, demolishers
	Which life cycle environmental assessments tools are used during the design process?	investors, designers
	Are life cycle economic or environmental assessments used during the waste treatment (to assess the destiny of waste)?	waste managers, demolishers

Semi-structured interviews were conducted for this work with different stakeholders of the building value chain from five European countries, between 2019 and 2020. The semi-structured interviews, consisting of open-ended questions related to the topics to be discussed during the interview. The sequence of the questions and the style of conversation changed in relation to the responders, to create a confidential environment of knowledge exchange, pursuing a dialogue and capturing informants' views. The methodology is already validated by other scientific studies, for example: Densley Tingley et al. (2017) interviewed 13 construction industry stakeholders to understand and overcoming the barriers to structural steel reuse; Kanters (2020) had a semi-structured interviews with 10 architects and 2 consultants to deduce how architects are dealing with translating the principles of the circular economy to the building sector; Cruz Rios et al. (2021) interviews with 13 architects to understand the challenges and opportunities for circular building design; Kirchherr, 2018 interview 47 expert among businesses, policy-makers and academics to the detect the main barriers that slow down the transition towards a CE in the EU; Yuan, H. (2017) interviews 10 stakeholders with government staff and industry to find the most critical challenges and promising countermeasures of managing CDW; Høibye and Sand, 2018 conducted, in the Nordic countries, 16 interviews to specialist employed at universities, public authorities and industry organisations in order to identify potential policy instruments that can accelerate a transition toward a circular economy.

The respondents were chosen through a sample of respondents, selected by authors and based on their knowledge of the topic under investigation (Kirchherr et al. 2018). The sample of respondents, defined by authors, aimed at identifying the best public agency and private companies currently involved and interested in CE in the construction sector. The sample was composed by people already in contact with authors, considered with a high knowledge profile on CE in construction sector. The responders selected in the sample, have already experiences for CE in building sector, for example: operators involved in the building process of significant Circular Buildings like 'Circle House Project' in Denmark, 'Circular Retrofit LAB' in Belgium, and 'Circl Pavilion' in the Netherlands; stakeholders already involved in working groups on building resource efficiency, like Cost-Minea Action; academics or researcher with experience within CE at building level, like BAMB Project (Buildings As Material Banks, Horizon 2020); policymaker involved in the decisions of national circular economy roadmap.

Hence, a non-random sample of respondents were selected, in order to reach only stakeholders experienced in CE in the building sector. In fact, the random selection procedure was not suitable for this research, because the knowledge of the argument is not diffuse across all stakeholders of building value chain and, consequently, a randomization approach could have caused bias or it could have failed to highlight the virtuous paths in progress and the critical issues to be overcome.

From the sample, totally 38 stakeholders resulted available for an interview (approximately 85% success rate). The number of stakeholders selected has been enough to involve, in five different countries, at least one representative of all the key players of the construction process, namely: investors/owner, designers, manufacturers, suppliers, construction companies, demolition companies, waste facilities/treatment companies, and the stakeholders influencing the practices, namely policy makers, banks, and researchers/experts/consultants. The interviewed organizations are highlighted in the tables 3, under their consent (Høibye and Sand, 2018). Anonymity was ensured for organizations that preferred anonymity.

Each stakeholder received an interview guide before the interviews were conducted. One author of this paper conducted all the interviews across the five EU countries. Interviews lasted between 60 min – 120 min, depending on the interviewee, and they were carried out face-to-face as well as virtually via Skype. Interviews were tape-recorded and then transcribed, coding the point of view of responders in order to define the current initiative in policy and practices, the current application of sustainability assessment and the related barrier and drivers within the 9 CE strategies defined by literature (table 1).

Table 3. Overview of interviewed stakeholders across the five European countries.

Stakeholders	Country	Interviews		Code interviews
policy makers	BE	OVAM	face-to-face-interview	BE1
	NL	Ministerie van Binnenlandse Zaken en Koninkrijksrelaties	virtual-interview	NL1
	UK	Expert (Building Research Establishment)	virtual-interview	UK1
	DK	The Danish Environmental Protection Agency (EPA)	face-to-face-interview	DK1
	IT	Expert (Politecnico di Milano)	face-to-face-interview	IT1
investors/ advisors/ banks	BE	Montea	face-to-face-interview	BE2
	BE	Belgian bank (anonymous)	face-to-face-interview	BE3
	NL	ABN/AMRO	face-to-face-interview	NL2
	DK	GXN	virtual-interview	DK2
	IT	COIMA	face-to-face-interview	IT2
	IT	Italian bank (anonymous)	face-to-face-interview	IT3
designers	BE	Expert (VUB)	face-to-face-interview	BE4
	BE	Expert (VITO)	face-to-face-interview	BE5
	NL	Rau Architects and Madaster	face-to-face-interview	NL3
	UK	Expert (Loughborough University)	face-to-face-interview	UK2
	DK	JJW Architects	face-to-face-interview	DK3
	IT	Engineering and Architecture Italian firm (anonymous)	face-to-face-interview	IT4
manufacturers	BE	Steel Supplier & Manufacturer (anonymous)	virtual-interview	BE6
	NL	Ahrend	face-to-face-interview	NL4
	UK	Designer and manufacturer of ceiling, wall and suspension system solutions (anonymous)	virtual-interview	UK3
	DK	Gamle Mursten	face-to-face-interview	DK4
	IT	PICHLER Projects	face-to-face-interview	IT5
construction companies	BE	Van Roey	face-to-face-interview	BE7
	NL	Boele & van Eesteren, company of Royal VolkerWessels	face-to-face-interview	NL5
	UK	Construction Company (anonymous)	virtual-interview	UK4
	DK	Expert (MT Højgaard and Aalborg University)	virtual-interview	DK5
	IT	National Association of construction company (ANCE)	virtual-interview	IT7
demolition companies	BE	Expert (VITO)	face-to-face-interview	BE8
	NL	New Horizon Material Balance	face-to-face-interview	NL6
	UK	NFDC	virtual-interview	UK5
	DK	Expert (Teknologisk Institut)	virtual-interview	DK6
	IT	Corbat	face-to-face-interview	IT8
	BE	Tracimat	face-to-face-interview	BE9

waste managers	BE	Expert (VITO)	face-to-face-interview	BE10
	NL	Urban Mining Collective	face-to-face-interview	NL7
	UK	Expert (Building Research Establishment)	face-to-face-interview	UK6
	DK	Expert (Odense municipality)	face-to-face-interview	DK7
	IT	Società Italiana Demolizioni	face-to-face-interview	IT9

2.2 Cross-comparison analysis

To analyse the data collected from the interviews, a cross-comparison analysis was conducted, as already done by other scientific studies to comparing policy and practices across different countries (Alves, 2018; Hennes et al., 2015; Kim et al.,2014).

According to Kim et al. (2014) transnational cross-comparative research makes it possible to overcome national paradigms, which can limit the scope of observation, opening to new research questions. Moreover, the comparison can also help to measure the results that, within a single national context, may be not relevant, and by comparing practices and their effects in different countries, lessons can be learned and replicated in other contexts, further improving the practices themselves (Kim et al., 2014; Alves, 2018).

To conduct cross-comparison analysis a matrix, used an information organizational tool, was arranged. The information is set up by arranging the analyzed strategies in row and the analyzed impact in column.

All the interviews were revised, collecting all information regarding: best practices, respondents' personal opinions, barriers or levers identified by the respondents. The analysis of the information made it possible to evaluate each CE strategy from 1 to 3 points, with respect to the application level. For each strategy analysed, the matrix indicates the level of application in the policy dimension, in the practical dimension and in the sustainability dimension. The application level is represented by the number of boxes ticked, as shown in the cross-comparison diagrams: three boxes indicate the maximum application level; two boxes indicate a medium level, one box indicates a minimum application, and no box ticked indicates 'not yet applied' (Fig. 2).

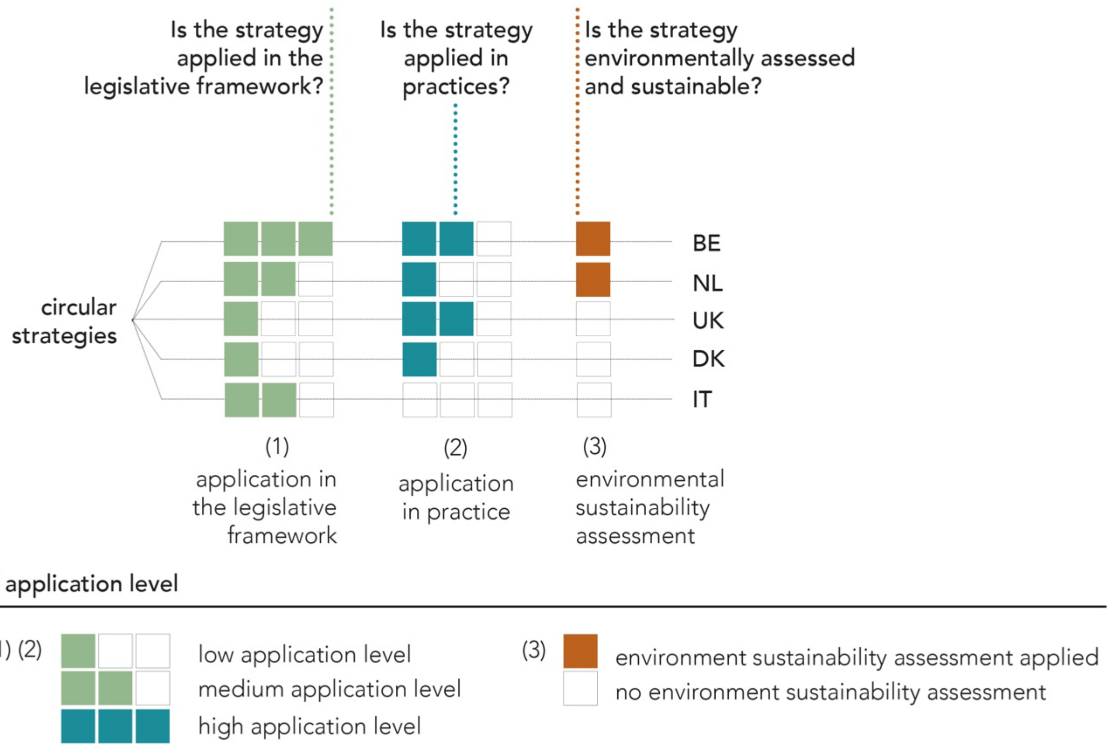

Figure 2: Methodological representation for cross-comparison analysis. For example, in the policy dimension, a maximum level (3 boxes ticked*) of application occurs when a CE strategy (e.g., traceability*

system) is supported by legislation, through organized systems, and concern the whole construction sector. A medium level (2 boxes ticked*) occurs when the strategy is supported by regulation but only affects a part of construction sector, or a particular construction activity. A minimum level (1 boxes ticked) occurs when the strategy is supported by the legislation but concerns a small part of the construction activities or there is not yet a well-organized system for the fulfilment of the strategy, and, finally, no level (no boxes ticked) occurs when the strategy is not considered by the legislation*

3. Results and discussion: drivers, barriers and best practices in five European countries

3.1. Resource/waste management strategies

The first topic regards all strategies (incentives and obligations to avoid landfill of materials, component reuse practices, traceability support tools) useful to change the resource/waste management towards circular practices. The analysis shows a high level of application in the policies, but a low level of sustainability control. The legislative framework is moving mainly towards the elimination of landfilling through increased taxes, but an organized system of traceable material flows and the use of supporting tools for the control of materials leaving the 'urban mine' (e.g., pre-demolition-audit) are still not widely promoted and established. This lack in policy frameworks also has repercussions in practice, where in many cases virtuous practices are absent and material flows are not quantified and mapped. Figure 3 shows the cross-comparison, and each strategy is discussed below.

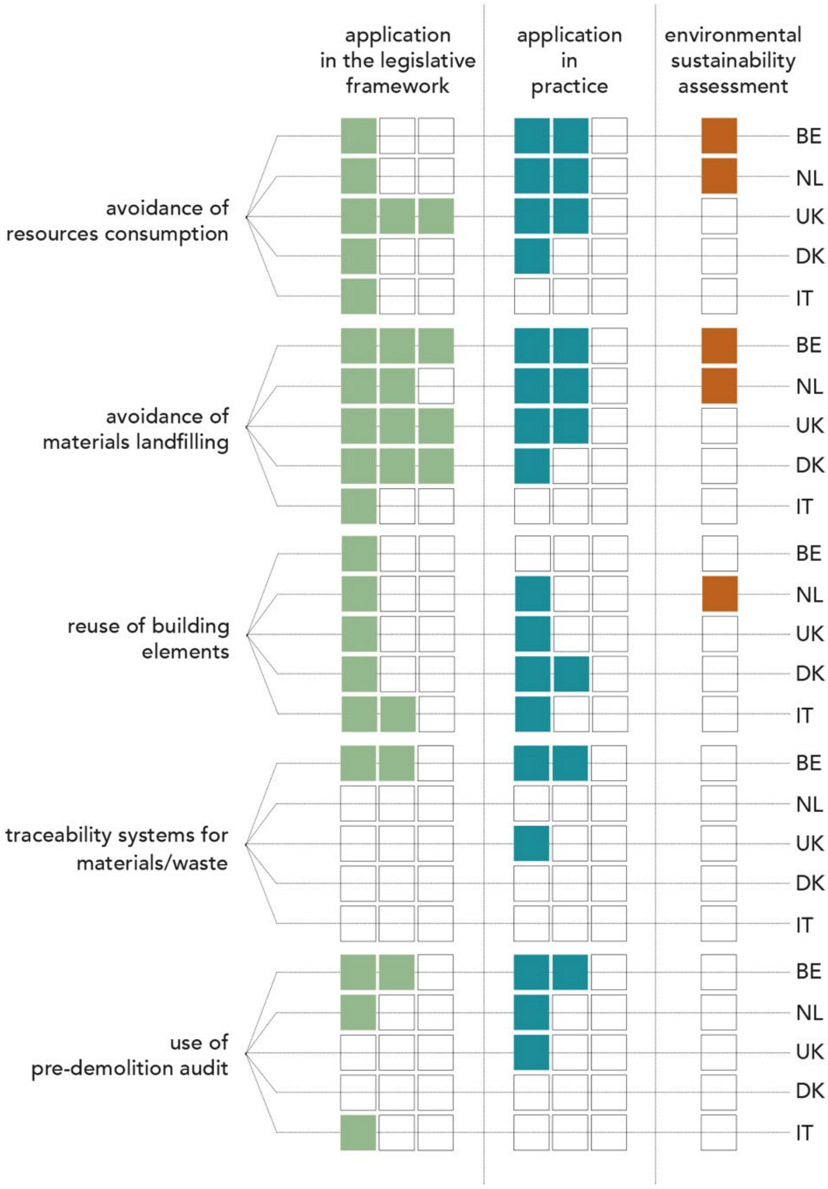

Figure 3: Cross comparison of resource/waste management strategies

3.1.1 Avoidance of resource consumption and materials landfilling

Regarding the strategy for the diversion of materials from landfill and the avoidance of resource consumption, as shown in Figure 3, in BE, NL, UK and DK, the legislation establishes specific bans or taxes to increase the fees of landfills[3], instead IT does not have a restrictive landfill ban, resulting in lower landfill fees compared with the other four countries. The high cost of landfill tax encourages stakeholders to prefer other types of waste destinations, in particular for inert waste, which are the heaviest waste fraction. Specifically, recycling practices that have lower access fees than landfills are preferred. The UK, as a territory with huge quantity of inert raw materials, imposes an Aggregates Levy in order to encourage the use of secondary materials. Whereas in Belgium and in the Netherlands the contextual characteristics, and the scarcity of raw materials, favour the recycling of existing materials, through the practice of urban mining, which was deemed

[3] *BL: Flemish Regulation on the sustainable management of material cycles and waste (VLAREMA), 2012; NL: Decree on landfills and waste bans (Bssa), 2015; UK: Tax on Landfill and Aggregates Levy, 2002; DK: law on taxation of waste and raw materials (Act No. 311/2011).*

economically advantageous compared to the import of raw materials. On the contrary, in Italy the inert raw materials are cheaper due to the high quantity available and the absence of taxes on them, so the use of raw materials is sometimes more advantageous than the use of secondary ones.

The legislation is fundamental to influencing the trade-offs between raw and secondary materials, encouraging the market demand towards circular practices. When analysing the prices of inert materials (Table 4), it is possible to note that the main economic levers to promote the preference of secondary raw materials instead of the virgin materials, are the difference in price between the raw materials and recycled materials and the cost of landfill. The comparison indicated that the minimum difference between virgin and recycled aggregates should be more than € 12 per ton, as in Belgium and in the UK where there is demand for recycled aggregate, and the price of landfill is more than € 100 per ton. When there is market demand, there are not logistics problems because the waste is stored for a short time. Moreover, Belgium, Netherlands and Denmark do not have high transport costs because they are not vast countries and the materials recovery facilities are very widespread throughout the territory. In the UK, a bigger country, it is common to use mobile plants for crushing the aggregate on site and save costs.

Table 4: Materials and landfill costs comparison among the five case countries (Sources: Flanders: interviewed expert estimation; UK: interviewed expert estimation and WRAP report "Gate fees 2018 Comparing the costs of alternative waste treatment options"; Italy: interviewed expert estimation and corporate price lists; Netherlands: "Resource Efficient Use of Mixed Wastes. National Fact Sheet"; Denmark: interviewed expert estimation)

	Price of virgin inert materials	Price of recycled materials	Differences between virgin and recycled aggregates	Gate fee of materials recovery facilities	Cost of landfill
BE	25 €/ton[a]	<10 €/ton	>15 €/ton	0 €/ton[b]	100 €/ton
UK	35 €/ton	23 €/ton	12 €/ton	26 €/ton	125 €/ton[c]
IT	10 €/ton	7 €/ton	3 €/ton	7 €/ton – 9 €/ton[d]	1 €/ton – 10 €/ton
NL	--	--	--	--	186 €/ton
DK	--	--	--	10-18 €/ton	64-110 €/ton

[a] depending on particle size distribution, quality.

[b] the gate fee can vary according to the quality of the materials, with the Tracimat certification a high-quality material can go to a crushing plant free of charge.

[c] 25 €/ton is the cost of landfill and 100 €/ton is the landfill tax.

[d] if the material mix presents other materials (e.g., wood, plastics) the price increases by more than 14 €/ton.

The stakeholders NL1, NL2, and NL3 identified the legislation introducing the use of Life Cycle Assessment as another important driver to reduce raw materials consumption and landfilling. In the Netherlands, the legislative decree '*Milieuprestatieberekening van gebouwen*' (art. 5.8 and 5.9), called MPG, indicates the mandatory reporting of buildings' environmental performance through an LCA study, for new homes and office buildings with a surface greater than 100 m^2. Since 1st January 2018 a maximum environmental impact limit value has been defined by legislation. The Netherlands' MPG legislation represents a possible best practice to be transferred to other countries, in order to achieve a sustainable transition towards circularity. This path could introduce the key operator of LCA sustainability experts, who carry out assessment and support decisions on circularity and sustainability.

A similar initiative has been identified within the Belgian (Flanders) policy plan. Since 2014, the political programme has promoted the development of a shared methodology for calculating buildings environmental impacts (MMG) and, since 2018, a simplified tool intended for designers, investors and policy makers, called TOTEM (Tool to Optimize the Total Environmental impact of Materials) based on the LCA methodology (OVAM, 2018) has been available. It is interesting to note that the MPG and MMG policies are based on the transformation of impact indicators into a single value through the monetization method (ISO 14008; Isacs et al., 2016; Pizzol et al., 2015), obtaining a 'shadow cost' value expressed in €/m^2 per year. This can be a relevant topic for circular economy, linking sustainability and economic value. Danish policy also proposes establishing a voluntary sustainability class in the building regulations, which over time may become a mandatory request[4].

An important initiative to encourage the reduction of raw materials consumption and landfill in Italy is represented by Green Public Procurement (GPP) (Legislative Decree 50/2016), according to which Public Administrations must integrate Minimum Environmental Criteria (CAM) in the field of public tenders. CAM require a minimum percentage of recycling, reuse, and disassembly of construction parts. Furthermore, Italy presents some reference practices: UNI/PdR 88: 2020, useful for verifying the recycled/recovered/by-product content, declared by an organization for its product, and UNI/PdR 75: 2020, which defines an operational methodology for selective deconstruction that favours the recovery (recycling and reuse) of CDW.

Regarding the legislative barriers, the stakeholders interviewed (IT1, DK1, IT8, and UK1) highlighted the absence of European coordination of policies for construction waste management and the lack of specific legislations in Denmark and in Italy[5]. This situation causes uncertainties about the type of procedures to which waste must be subjected in order to become new materials. A common definition of 'end-of-waste' criteria for CDW is necessary, also defining the documentation useful to certify the quality of recycled and reused materials. This implementation could overcome the current operators' distrust of secondary materials. Moreover, stakeholders highlight the need for a more detailed list of waste classification codes (European Waste Code, EWC Directive 75/442/CEE), since currently it allows the collection of different materials together into a single code, for example under the metals code (e.g., steel and aluminum) and for the insulating materials code (wood-based and plastic-based insulation together), discouraging separate collection of materials/waste.

Figure 3 shows that the legislative framework of BE, NL, UK, and DK has encouraged stakeholders to avoid landfilling in practices. However, even if the majority of CDW is recovered, only a minor part of this waste is recycled or reused directly for its original purpose; in fact, most of it is downcycled. The percentage of the Directive 2008/98/CE is currently satisfied by the treatment of inert waste, but the other fractions of lighter CDW, such as plastics (e.g., insulations and pipes for systems), are not considered, even if they can have a higher recovery potential and reduction of environmental impacts.

3.1.2 Reuse of building materials beyond recycling

Figure 3 shows that materials reuse is currently not widely promoted by national circular economy policies in the building sector.

In Italy, an important (indirect) lever for reuse is related to the bureaucratic procedures of public authorization, which entail much faster and cheaper procedures in case of renovation of a building (reusing existing parts) rather than total demolition of a building and new construction. For this reason, stakeholders prefer, when possible, to reuse part of existing building for economic and time advantages.

In the Netherlands, reuse is encouraged by MPG legislation (section 3.1.1), since reused materials generally contain less embodied energy and less embodied carbon.

Reuse is still poorly applied in practice, because there are still a number of barriers. The analysis of the stakeholders' perspectives highlights the lack of certification that establishes the quality, performance and technical characteristics of the reused materials as the main obstacle; in fact, there is generally no legislation

[4] Voluntary sustainability class in the building rules (2018) Presentations from the construction industry. Report, available at: https://www.innobyg.dk/media/75595/frivillig-baeredygtighedsklasse-br-18_final-rapport.pdf (access January 2020)

[5] In Italy, the CDW End of Waste decree is being defined. In May 2020 it acquired the favorable opinion of the state council.

regulating tests on reused products. In addition, the test procedure to certify a reused product is very expensive and takes a long time compared to the test procedures carried out to certify a new product that comes from a production factory. Without certification, constructors and architects do not want to have the responsibility of the quality of reused materials in the new building.
Another important barrier, highlighted by the stakeholders (BE7, NL5, UK4, DK5, IT7, BE8, NL6, DK6, and IT8), is represented by the economic aspect, in particular regarding the cost of contractors to enable reuse of materials. The careful removal of components and parts is too expensive compared to the potential savings obtained by reusing the same materials, or the potential gains that can be made by selling the reusable material, especially when it is difficult to identify a potential market. Stakeholders (BE2, BE4, UK2, DK3, and IT4) also highlighted challenges from technological aspects: current technological systems are not designed for disassembly; therefore, it is difficult not to damage the elements during disassembly. Other barriers include the space required to stock the disassembled materials before the reuse, in particular for urban districts, and the logistic system for reused materials has not yet been developed.
Currently, materials reuse is mainly an informal market of high value building components, without specific performance requirements, sometimes supported by exchange platforms which link the supply and demand of secondary building materials. However, the investigation across the five European countries has singled out a best practice of reuse in Denmark, regarding the reuse of old bricks, which is becoming popular particularly for the public buildings. This practice is possible thanks to a specific certification process to allow the return into the market of certified second-life bricks. Other best practices can be found in the biggest construction companies in Denmark and in UK, which are creating an internal reuse of construction waste, activating a materials exchange among their on-going open building yards. In this case, the reuse practices are constituted mainly by residual and cut-off materials in the construction phase. Some companies take back their products and materials from construction waste (residual and cut-off) to reuse them on another site or to re-introduce them into the production process. However, it is important to highlight that the presence of residual and cut-off materials (pre-use) should be avoided optimizing the construction process. It is therefore a less relevant type of reuse than the end-of-life one (post-use).

3.1.3 Traceability system for materials/waste and pre-demolition audit

Stakeholders (BE1, UK1, BE9, BE10, and UK6) consider the improvement of traceability systems of materials/waste and the use of the pre-demolition audit as strategies to improve materials circularity. In particular, Figure 3 shows the main level of application a traceability system, linked to legislative initiatives, in BE, and linked to stakeholder initiatives in the UK. Furthermore, it is possible to note that pre-demolition audit is encouraged, in Belgium, the UK, the Netherlands and in Italy, boosted by legislative requirements.
Belgium (Flanders) sets a system for materials traceability, called Tracimat (VLAREMA, article 433) which controls the drawing up of pre-demolition audit and the demolition inert waste monitoring. The Tracimat system is currently mandatory only for a part of buildings[6], but in order to spread it on the whole building stock, as a good practice, an economic driver is applied. The Belgian (Flemish) legislative framework, in fact, establishes that materials that have not undergone the traceability process have higher cost when conferred to recycling. For this reason, stakeholders are encouraged to apply the traceability process to have discount on gate-fees of recycling plants.
The UK, in order to improve waste management, set up a regulation called 'Site Waste Management Plans' in 2008. This legislation required contractors to foresee the quantity and management of CDW, to monitor waste/materials, and to declare the levels of reuse and recycling actually achieved. Although the 'Site Waste

[6] for non-residential buildings >1000 m^3 and residential buildings >5000 m^3

Management Plans' are no longer mandatory, there are stakeholders (mainly contractors working for large construction projects) who still do it as a voluntary activity, because it is a good and cost-effective practice.
In Italy the CAM of GPP promotes the use of pre-demolition audit[7], assigning the duty to the contractor, but currently the stakeholders (IT4, IT7, IT8, and IT9) declared that it is rarely applied in practice.
The analysis highlighted the traceability systems and the use of pre-demolition audits adopted in Belgium (Flanders) and in the UK as potential best practices that can be replicated in other countries. Thanks to the support of legislation that determines its economic convenience (lower cost gate fees at recycling plants for contractors), stakeholders are encouraged to implement the procedure and extend it voluntarily to the entire building stock. Furthermore, the introduction of traceability systems leads to the need to involve new roles and new operators along the construction process, to complete and follow the entire procedure, such as completing the pre-demolition audit, performing data analysis, monitoring the demolition work, and checking the correct separation of materials.
However, to achieve a more efficient end-of-life management towards upcycling and reuse, a common traceability system is needed to monitor all fractions of materials/waste (not only aggregates) and to cover the entire process starting from the decision to demolish a building, considering also the possibility to avoid waste through the life cycle extension of building parts (not only when the demolition is already decided). Moreover, it is necessary to emphasize improvements towards sustainability (not only circularity) combining the use of pre-demolition audit with LCA methodology in order to assess the most environmentally sustainable solutions of construction end-of-life management.

3.2. Design strategies for reversible building

The second topic concerns all the strategies (reversible strategies and digital technology in design and construction through BIM, and material passports, and decision-making support tools such as building sustainability certification) useful for transforming traditional building design towards a circular building design, conceived with a life cycle thinking.
The survey shows that the main incentives are aimed at the diffusion of BIM, but there is still little promotion in the legislation on reversible design strategy and on the use of material passports. Some best practices, on the other hand, arise from private initiatives, guided by experimentation and a competitive approach to sustainability and circularity. The figure 4 shows the cross comparison and each strategy is discussed below.

[7] National action plan on Green Public Procurement (PANGPP), point 2.5 "Construction site technical specifications".

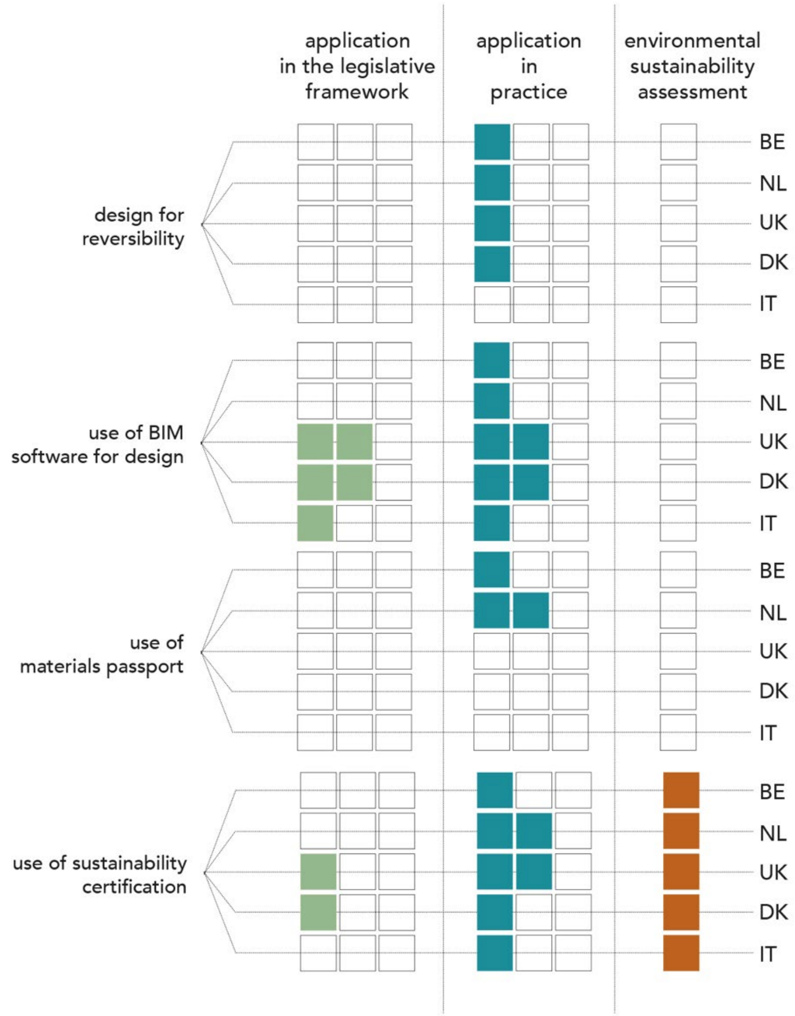

Figure 4: Cross comparison of design strategies for reversible building

3.2.1 Construction technologies for a reversible building

The cross-comparison reported in figure 4 highlights that in the legislative framework of all five countries a specific regulation for promoting reversible construction is lacking. Instead, there are bottom-up initiatives in practice, applied by private companies and driven by market competitions. Policy makers (BE1, NL1, UK1, and IT1) show that there are difficulties in developing a legislative framework to improve a reversible construction process and introducing new design and management rules, because there is no shared awareness of the meaning of 'reversible building' as a relative new way to design and build.

Taking up the stakeholders' perspectives (BE4, DK3, IT4, BE7, UK4, DK5, and IT5), the main barrier is related to the economic aspect. Currently, a larger investment is required to construct a reversible building than a traditional building, due to the need for more skills during the design and construction process. Nevertheless, some investors (IT2, BE2, BE3, and DK2) are attracted by the opportunities to increase market value, deriving from the increase in the capacity of use, rent or sell the building, from the reduction of the investment risk, and from the decrease of maintenance and transformation costs, thanks to the flexibility and adaptability of the building. From the designer's point of view (BE4, UK2, DK3, and IT4), an obstacle to the construction of a reversible building mainly concerns the difficulties in finding easily removable building products on the market. On the other hand, from the point of view of manufacturers (BE6 and IT5) there are few market demands for dismountable products. The promotion of requirements related to reversible buildings through policies could activate the demand and consequently the offer of reversible construction solutions. Another obstacle highlighted by the interviewees (BE4, NL3, UK2, DK3, and IT4) for a reversible building concerns obtaining legal authorization for the construction of a reversible building. The current mandatory documents, necessary to obtain building permits from the public administration, are based on static structures and do not consider the possibility of building modifications during use.

Stakeholders interviewed (DK5, BE4, BE7, NL2, and NL7), involved in the construction of reversible experimental buildings (e.g., the 'Circle House Project' in Denmark, the 'Circular Retrofit LAB' in Belgium, and the 'Circl Pavilion' in the Netherlands), highlight that to build a reversible building, the entire management of operational and organizational models have to be changed. In a traditional construction process, most operators are accustomed to making many decisions along the construction process, step by step, based on a series of phases carried out by different operators, who collaborate in a 'vertical' way, sometimes with many communication difficulties. In a reversible construction process, multiple interdisciplinary interactions are needed from the initial stage. The decision-making process is based on a co-creation between owners, designers, builders, and manufacturers of materials, who collaborate in a 'horizontal' way. In this case, the design phase plays an important role and the design times generally lengthen, in order to define all the details (reversible construction technologies and strategies to optimize material flows) in advance. The time needed for the construction phase, however, is shorter because it is better planned. For this reason, the stakeholders (DK5, BE4, BE7, NL2, NL7, BE2, IT4, and UK4) identify the necessity of a key-expert-operator (one person or one company) that can manage and follow the entire circular building process, from the beginning to the final realization, in order to ensure compliance with all circular objectives set by the origin of the project.

To achieve reversible building process, several aspects need to be strengthened in all countries. Firstly, it is necessary to incentivise (economically) the industries towards the production of reversible building technologies, and to spread the knowledge of the assembling and disassembling practices. Secondly, it is necessary to incentivise (economically) the investors to prefer a reversible building, encouraging a building life cycle thinking. It is necessary to spread stakeholders' awareness of economic and environmental opportunities of the extension of product life and sustainable end-of-life management. Thirdly, it is necessary to encourage a building process that create relationships among stakeholders (in particular designers, constructors, manufacturers, and demolishers) in order to shared knowledge and information on reversible strategies, from the beginning of the project and across all building process.

3.2.2 Use of BIM and materials passport

Figure 4 shows that the use of BIM, in some cases, is also imposed by legislation, as in Denmark, in Italy and in UK[8]. BIM requirements during the design phase enable efficient information sharing throughout the supply chain, reducing the risk of building design errors and waste during the construction phase. This requirement implies the need to increase the digital technology capacity of all operators involved in the decision-making design of the building, sometimes through specific training. However, the legislation set a requirement for the use of design BIM digital tool, only in regard a part of public building.

In DK, companies that want to bid for government, municipal or regional construction contracts, over a cost limit, must meet requirements on digital building models. The government sees potential in using digital models to optimize design and execution. Based on the requirements to be met, the digital information about the project must be processed during the construction phase and organized as documentation of the construction project and as a direct basis for the future management of the building.

[8] Denmark: ICT regulation n. 118 of 06-02-2013 and n. 119 of 07-02-2013; Italy: DM 560/2017; UK: Government Construction Strategy 2016-20.

In public construction, Italy requires the use of interoperable tools, which can be used at any stage and by every operator during the design, construction and management process of the building. The requirement concerns public construction activities over a cost limit, which decreases every year to reach, by 2025, the majority of public interventions.
Since 2016, the UK government, has embarked on a requirement to embed and increase the use of digital technology on procured government construction, asking for a 3D BIM Level 2. The use of Building Information Modeling (BIM) Level 2 is required to facilitate the reduction of construction waste.
As a result of the legislative boost, in practice the use of BIM is quite widespread, but in the case of building without mandatory BIM requirements, the real potential of the tool for mapping information along the life cycle of the building and for increasing and coordinating interoperability among the operators who act along the building process, is not fully exploited.
According to stakeholders (BE3, NL2, DK2, IT3, BE4, NL3, UK2, DK3, BE6, BE7, DK5, NL6, and NL7) the use of the material passport could be a solution to increasing knowledge of materials stored inside the building, essential for increasing the chances of reuse and recovery. Using material passports capable of storing information about materials and products, can also implement a database of building materials flows that encourage large-scale flow management and monitoring.
Material passports systems and databases can interact with BIM software and can be available to all users involved. Nevertheless, no countries have already introduced legislation on mandatory use of material passports, since a common definition and harmonized tools / systems are lacking.
The use of materials passport has been promoted by private initiatives such as 'Madaster' in the NL and project initiatives in BE (within BAMB Horizon 2020 Project). The Madaster platform aims to map the entire Dutch real estate assets, in order to know the flows of materials in "depot" and in "mine". The materials in depot are those stored in buildings that have been registered during their construction, and therefore that are registered in advance, with all their characteristics. This is a more efficient practice than completing an inventory afterwards. The materials in mine are those contained in the existing buildings, which do not have a passport from their origin and have to be remapped for knowing the qualities and the location of materials. According to Madaster, knowing the characteristics of the materials also makes it possible to know their residual value. The concept of conserving the (economic) value of materials is an objective of material passports. Knowing and preserving the (economic) value could be an additional gain for selling the materials stored in the building at the end of its useful life: this concept is very interesting for investors and owners. In this context, the Madaster initiative in the NL could be a best-practice to be transferred to other countries.
The introduction of materials passports involves the need for a 'materials passport expert' across the construction process (according to NL3, DK3, BE4, and BE7), such as a professional operator, connected to designers, manufacturers, and contractors, responsible for mapping all components and materials characteristics and define the residual value at the end of life.
To trigger sustainable (and not just circular) processes, it is therefore necessary that design digital technologies, such as BIM and material passports, also report the environmental profile of the materials/products considering their entire life cycle (for example, using environmental certifications such as EPD-Environmental Product Declaration).
Nevertheless, the survey shows that in policy framework and in practice the coupling between digital design technologies and environmental sustainability tools is not promoted. The assessment of environmental impacts with LCA and economic impacts with LCC, combined with BIM and material passports, evaluating the environmental impacts and market opportunities could influence the decision-making process, in particular:
- during the design process, for the choice of different design solutions (e.g., renovation rather than demolition; reversible technologies instead of traditional ones), and construction solutions that avoid unnecessary waste to maximize the value and sustainable use of materials.

- during the management of the end of life, for the choice of the different types of demolition, and the destination of building elements or materials (e.g., between reuse or recycling), to promote resource efficiency and sustainable waste treatment.

3.2.3 Use of sustainability certification to orient design

The respondents (UK1, IT2, DK3, IT4, IT8, IT9, and UK6) highlight the crucial role of building sustainability certification (e.g., a green building rating systems), which can influence the building process towards circularity and sustainability, with added value in terms of increasing building economic value, lowering maintenance costs, and enhancing wellbeing and visibility for occupants. The use of building sustainability certification, through reward mechanisms, favours the development of circular practices not yet commonly applied and helps them optimize and lower costs for all the stakeholders. Stakeholders (UK1, IT2, DK3, IT4, IT8, IT9, and UK6) highlight the use of sustainability certification as a lever to trace the materials in input and output and, sometimes, to demonstrate the impact assessment of intervention through LCA.

As shown in figure 4, generally, the use of building sustainability certification is mainly a voluntary, best-practice, accomplished only on icon buildings, but in some occasions, it is mandatory for public tender. In the UK, public procurements of local authorities and municipalities often require a certain level of BREEAM. The BREEAM identifies specific criteria for circular economy, not only for the 'use of reused/recycled materials' and the 'reuse/recycling CDW', but also regards 'design for disassembly', the 'design for adaptability', and 'pre-demolition audit'. Similarly, in Denmark many public buildings ask for the sustainability certification (generally DGNB) to be a 'manifest' of sustainability of the building stock.

In the Netherlands, it is important to highlight the work done by the DGBC (Dutch Green Building Council) on the proposed improvement of BREEAM-NL (New Construction and Refurbishment and Fit-Out based). The proposal give six addition indicators about: 'Design for reassembly', which requires de/remountable connections for products, and 'Knowledge development and sharing' which requires building materials passports and buildings' specific 'disassembly guidelines'; and nine improvements about 'maximizing amount of reused materials and renewable materials' (DGBC, 2018).

The building sustainability certification, through specific criteria, encourage also the use of the LCA as a tool to demonstrate the actual environmental impacts avoided by materials and construction solutions. This represents a practical link between the encouragement of circular practices and the assessment of environmental sustainability.

3.3. Business strategies and stakeholders' networking

The analysis shows that the application of business models and stakeholders networking based on circular strategies are still less applied both in legislation and in practices. This highlights that the potential economic and environmental potential advantage regarding the introduction of new service-oriented business and operators' networking systems, is still unknown. Nevertheless, based on the example of the best-practices, the study shows that application of new circular strategies leads to the need of new operators with specific competence across building process, meaning new job opportunities.

The figure 5 shows the cross comparison and each strategy is discussed below.

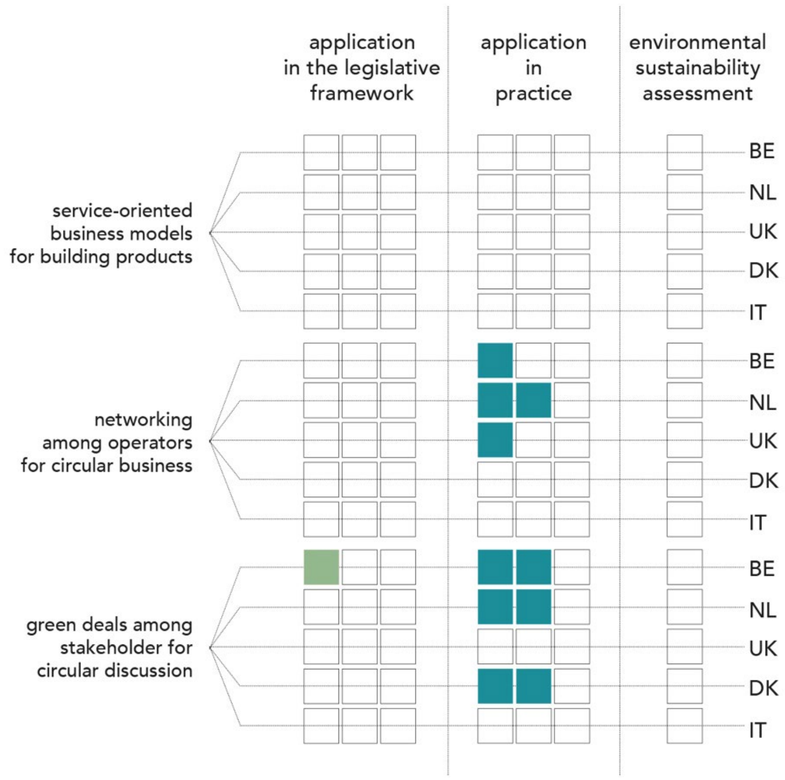

Figure 5: Cross comparison of business and stakeholders' networking strategies

3.3.1 Service-oriented business models for building products

It is clearly shown in Figure 5 that the application of service-oriented business models at building level are still poorly applied both in legislation and in practice in all the case-study countries. This highlights that the application of service-oriented business models at building level should be further explored. Despite the stakeholders' interest (IT2, IT3, NL2, DK2, NL3, and BE6) in the possibility of changing their business, the application of new business models shows some complications at the building level.

The complications regard the peculiar long life of buildings, therefore, maintenance interventions and the end of life of the products take place with extended times, not typically faced by a company. Consequently, the formulas for maintaining ownership of the product by the manufacturer and for renting the product (e.g., pay-per-use) with the provision of the management service are difficult to apply.

Regarding the opinions of the stakeholders interviewed, investors (BE2, NL2, DK2, IT2, and IT3) perceive opportunities in a service-oriented business models, such as less risks of investments and less cost of maintenances due to the continuous use of products in a good condition. However, many obstacles are highlighted by the banks (BE3) which finance companies and private persons. From their point of view, a building with different parts not owned by a single entity but based on service-oriented business models is a riskier investment, for the possible bankruptcy of the companies that provide services. Stakeholders, in particular investors and producers (BE3, BE2, IT4, NL2, DK3, BE6, UK3, DK4, and IT5), highlight the doubts they have within fiscal barriers, because the regulations do not contemplate the situation of a company that does not hold property but only rented services.

The examples regarding product-service-systems applied at building level are related only to movable and short lifespan elements such as furniture (NL4), or products which give a service such as heating or lighting, and take-back materials' schemes for materials with a high residual value such as steel structures (Wang, 2017).

3.3.2 Networking among operators for circular business

The interviews show that the stakeholders (NL6, DK6, BE10, NL7, and UK6) are interested in linking with others to open new businesses based on product reuse/remanufacturing. However, the company interviewed (DK4) explains that, currently, the communication regarding the availability of material extracted from urban mining and market demand, takes place only informally between operators, who are not constantly connected to each other.

The building sector is characterized by very different interventions from time to time, by unstable processes (unlike the industrial sector), whereby each building process activates different operators who temporarily work together. For this reason, supply chain operators are unlikely to establish stable relationships over time. This also makes it difficult to activate synergies between operators who have roles in different phases of the life cycle.

As shown in figure 5, networking initiatives are present in NL, starting from voluntary practices (without legislative support). The interviewee (NL7) shows the establishment of partnership competences (between demolisher, waste/material manager, logistics, and building materials producers) to open a business based on 'urban mining' through reuse and recycling materials. This partnership ensures an immediate exchange of information and facilitates a process of reuse (and recycling) with agreed prices and costs.

Some platforms have been developed in order to encourage the relationships and the information sharing among the operators of the building value chain. Digital exchange materials platforms connect the supply and demand of secondary building materials; examples are: Opalis, in BE; Globe Chain, Recipro, Enviromate, Builders-surplus, and Excess materials exchange in UK; and Harvest Map in NL. These platforms can be important in creating new business, because they show not only the available products, but also the services provided by the professional operators (such as dismantling and cleaning, tailoring elements, and specialized advice). Moreover, these platforms offer technical information on the building products of the re-use market: their main characteristics, the frequency with which they are released, availability, indicative prices, and some examples of successfully reuse. Nevertheless, stakeholders (DK3, BE10, and UK6) state that these platforms are not widely available, and they are mainly used by operators for private purposes. Moreover, the platforms currently in use do not consider the environmental impacts but only return a quantification and a location of the materials available on the market.

It would, for example, be fundamental to calculate the maximum distance to which a secondary product could be transported, in order to respect the impact threshold, compared with the production of a similar new component.

3.3.3 Green Deal among stakeholders for circular discussion

An important initiative underlined by stakeholders (BE1, NL1, BE2, BE3, NL2, BE5, BE6, and BE7) is the 'National Green Deal', which started as a boost for the collaboration between government, companies, and institutions to incentive circular economy, removing circularity obstacles in legislation and practices.

As shown in figure 5, in BE, a 'Green Deal Circular Building" (GDCB) was established in 2019, on the initiative of the Belgian government (Flanders Circular, OVAM) and the Flemish Construction Confederation, within the Flemish Circular Programme, signed by 300 companies and institutions, involving governments, construction builders, producers of building materials, architects, banks, property developers, research institutes, and universities.

An important initiative of GDCB is the "Circular Building Living Lab", led by VITO, BBRI, Hasselt University e Vrije Universiteit Brussel and OVAM. The aim of this Living Lab is to draw up policy and practical recommendations, based on "an experimental field" of practical experiences and research results, to accelerate the transition to a circular economy in construction.

Relevant data are collected from real-time experiments. Living labs creates places for the exchange of research experiences and results, an environment for discussion with the stakeholders involved, leading to the definition of solutions for changing practices and policies. In the first phase (2019-2020), the activities within the Living Lab were focused on "urban mining" towards reuse or high-quality closed-loop recycling. The Living Lab focused on responding to technological and non-technological possibilities for better sorting current construction and demolition waste on site, recycling and/or reusing it in useful applications.
In a second phase (2020-2022), the Living Lab is focusing on "change- oriented (re)building", as well as on the designing, building, collaborating and creating value seeing buildings as material banks.
In the NL, with the Green Deal approach, the government is providing support for innovative initiatives to accelerate the transition to a sustainable economy. The 'Green Deal Circular Buildings' started from early 2015 and last around four years. The Dutch GDCB included building stakeholders and many Dutch Ministries, and focused mainly on the existing buildings. In particular, they worked on existing office buildings, which are being renovated (building interior or exterior) over a period of 15 years, a phase that offers many opportunities and possibilities for activating circular dynamics. They are working with the aim of providing suitable tools to assess the circularity of a building. To this end, the GDCB has developed a circular passport, which describes the circularity of buildings and a circular manual that supports and explains how buildings become circular. In DK, an important bottom-up initiative is the VCØB (Videncenter for Cirkulær Økonomi i Byggeriet), developed by a consortium of voluntary stakeholders. It is a virtual place to share knowledge for circular economy in the building sector. The aim of VCØB is to collect, develop, and spread a knowledge about the circular economy in construction sector, providing information on current standards and best practices.

4. Concluding remarks

The transnational cross-analysis showed the lack/inadequacy of current legislation and policies and the need to overcome barriers and define drivers, directly involving stakeholders in the policy definition process, with a more participatory decision-making process.
The analysis shows that strategies towards the circular economy currently are diverse and fragmented among the countries analysed, and not equally encouraged. Therefore, more effective and coordinated actions and policies should be promoted by European Commission.
Regarding the resource and waste management strategies, the analysis shows that the current legislative framework considers mainly recycling strategies, with a quantitative (and not qualitative) approach; while reuse strategies and targets oriented towards reuse should be promoted.
To improve reuse strategy, on a local scale, there is the need to foster stakeholder networking and to locally manage the flow of materials. On the other hand, on a European scale, it is important to encourage coordination, for the development of harmonized supporting guidelines and tools, in particular for the definition of end-of-waste criteria, traceability guidelines, pre-demolition audits, and material passports.
Regarding the design strategies for reversible building, the cross-analysis highlights the need to define a shared meaning of design for disassembly and reversibility, to set design criteria, principles and procedures in the legislative framework (a first step was the definition of standard 'ISO 20887:2020). Furthermore, the need to develop and co-create disassemblable building products is necessary, increasing market demand, for example through specific requests in public tenders. The training of new professional figure with specific skills and the increasing interaction among BIM, materials passport and LCA, LCC is a pressing issue. Information and Communication Technologies (ICT) in fact should be an important field for defining supporting tools towards a sustainable and circular building design and management across building life cycle.

In the field of business strategies and stakeholders networking, a harmonization of enabling tools (digital, platforms, traceability) is needed to promote the creation of supply chains and networks between operators. The cross analysis shows the potential of innovative action to create networks along the value change, with government support for a green deal approach. The activation of Living Labs, through a combination of practical experience with scientific research, creates an important hub of knowledge and expertise, as an accelerator in the transition to a circular construction practice. Stakeholders' involvement enables definition of barriers and drivers to circular economy practices that could be useful in policy improvement.

Finally, the research focused on the need to evaluate the environmental effectiveness (sustainability) of circular strategies is not currently applied to most of the strategies and it is not supported by policies. To avoid the risk of activating circular economy strategies that are not effectively sustainable, the use of environmental and economic life cycle assessment tools becomes fundamental across the building process, through both political incentives, the development of digital support tools and formation.

The construction sector is resistant to change towards circularity, as operators tend to prefer traditional practices, with a low technological content. Furthermore, the relationships between operators are not stable throughout the building process (temporary aggregation for each individual project).

These peculiarities of the construction sector lead to the need to activate participatory co-creation processes (research, business, producers, builders) to identify shared innovative solutions, overcoming the current barriers. The involvement of stakeholders and co-creation will gradually overcome scepticism regarding circularity (distrust of reused and recycled materials by customers; distrust on the part of operators and the problem of responsibility).

To activate a transition towards circular economy, stable supply chain relationships must be created by identifying new circular business models in a win-win solutions, based on services. Furthermore, it is necessary to promote changes both in tangible technologies (constructive, reversibility) and in intangible technologies (enabling tools and digital technologies, platforms, traceability systems). ICT is therefore a bridge between design, production, construction site, management and end-of-life and a way of information collection across the building life cycle. Top-down policies synergistic with bottom-up initiatives, and the dialogue among stakeholders, are important to enable the circular change of buildings value chain and practices.

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