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ORIGINAL PAPER

The Circular Economy and Circular Building Practices in Luxembourg

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Abstract
This article analyses the circular economy in Luxembourg using a retroductive approach to the study of practices. It presents the circular economy vision in Luxembourg as a governmental concept since 2015 that operationalises mainly within the building sector. Based on 66 semi-structured interviews with key stakeholders, the article expands on what circularity means for architects, engineers, and building firms. In this sense, the building sector in Luxembourg deals with three main topics: (a) circular design concepts, (b) circular materials management (i.e. materials passport), and (c) digitisation. The article discusses construction as a bundle of activities that constitutes shared meanings, materials, and competence. The findings illustrate that the circular economy foci in the literature and Luxembourg are path-dependent and mirror the European and national history of sustainability concepts in construction. If and how the circular economy and circular practices contribute to sustainable development in the country still needs consideration and monitoring.

Keywords Circular economy · Circularity · Building sector · Materials management · Design concepts · Luxembourg

Introduction

The rational use of natural resources has been essential in environmental policy since the European Commission (EC) foundation in 1967 [1]. It still holds an important place in current policies, i.e., the Circular Economy Package and the Green Deal. In 2011, the EC published the 'Roadmap to a Resource Efficient Europe' [2], followed in 2015 by an action plan for the Circular Economy (CEAP), updated in 2020 [3], and in 2019 by an overview of the implementation achievements of the latter, and in 2020 by the Green Deal [4]. In all these supranational documents, the building (and demolition) sector appears as one of the critical domains for recovering valuable resources. Moreover, it remains a priority

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for research, innovation, and investment because the sector is intensive in labour, natural resources, and capital [5].

Circularity in building started with sustainable construction principles established in the mid-1990s. It adds to the traditional concerns of performance, quality, and cost, environmental challenges to highlight the (negative) impact of the sector on resource depletion and the state of the environment, e.g., air quality and land use [6]. Today, the sustainability concept in construction and demolition interweaves with the circularity concept and closely connects with the life cycle perspective [7].

Studies clearly state a high potential for the circular economy at both European and national levels [8, 9]. However, concepts and practical guidance for transitioning to more circularity, especially at the company level, still need to be elaborated. In academia, deep concern has been given so far to innovation, technical systems, fiscal and business incentives, and reformulated business models as drivers for transformation towards a circular economy [10]. Nevertheless, more needs to be said about the socio-political implications and possibilities for shifting current production-consumption-use-waste practices [11, 12].

Production-consumption-use-waste practices are the social phenomenon of study interest from diverse angles. Emphasis often lies in analysing the behaviour of producers and consumers, especially towards policy changes. Therefore, social practice theories (SPT) consider practices as the central unit of analysis. This angle permits research after implementing a new policy, the transition from one practice to another. Authors claim that this focus enables overcoming weaknesses due to limited analytical categories in studying social phenomena, e.g. attitudes and preferences of individuals, norms, values, discourses, or social structures [13]. In this sense, the building sector in Luxembourg is analysed from a social practice theoretical perspective after implementing a circular economy vision in the 2015 governmental program.

The remainder of the article is as follows: "Operationalising the Study of Circular Practices in Construction" deals with literature regarding the circular economy in construction and policy and operationalisation schemes for practice research. "A Qualitative Approach Toward Circular Practices" outlines the method applied to analyse sustainable building practices, while "Circular construction practice(s) in Luxembourg" deals with the building industry in Luxembourg, followed by a discussion of the findings and conclusions in "Discussion and Conclusions: Drivers Are Governmental and Path-Dependent."

Operationalising the Study of Circular Practices in Construction

This article presents the circular economy from the perspective of the building industry and, with the lens of social practice theories, as a bundle of sustainable construction practices. The following sections first discuss the literature on sectoral insights into the circular economy and then approaches to study practices with a geographical and social science perspective.

Circular Economy and the Construction Sector

Popular discourses on the circular economy often pick out as central themes the changes in design, production, consumption, use, waste, and reuse practices accompanying the shift from a linear functioning of the economy to a system in loops. Those accounts reveal an understanding of a circular economy as an assembly of economic activities that are circular and sustainable.

Research on circularity in the building sector focuses primarily on the recycling of construction and demolition waste [14], life cycle approaches to construction materials (incl. ecodesign), and the performance of buildings and construction works (incl. energy efficiency, operating costs, and user satisfaction) [10]. Most of the research programs emanate from engineering departments and follow a performance perspective for the planning, design, construction, operation, maintenance, and deconstruction of buildings and construction works. In this sense, authors claim research gaps in the reuse of products [15]. Integrative and multiperspective approaches to circularity and sustainability in construction require research on the built environment, legal and procurement practices, regulation, information, and documentation [16].

Research on policies for a circular economy reveals that an efficient policy mix should promote three areas that are underdeveloped in existing policies at the EU level: (a) policies for reuse, repair, and remanufacturing; (b) public procurement for resource efficiency; and (c) strengthening secondary resource markets [17]. This materials-centric approach in the policy mix would overcome the identified waste-centric landscape in the current EU policy [17]. At the business level, circular economy policies are generally considered a driver (when present) or a barrier (when absent). National governments can actively support a transition towards a circular economy by providing direct/indirect financial support, training, and education [18]. At the same time, laws and regulations at the EU level can make it necessary to provide new solutions in the case of prohibitions, for instance [19]. Empirical studies show that companies, especially when they are already advanced actors in sustainability thinking and practising, ask for stricter regulations. Stricter regulation provides early movers in sustainability/circular economy with a competitive advantage [20] until competitors comply with the new requirements.

Operationalisation Schemes for Practice Research

Different scholars in human geography focus on the study of practices for analysing socio-economic phenomena in relation to each other [21, 22]. Practices are the central building blocks of the social world and the basic organising unit of all social phenomena [23]. Practice theories explain social phenomena as a bundle of practices in a specific context, ranging from individual activities to complex societal developments [24]. The conception of economic activities as a bundle of social practices allows linking individual actions with overarching economic processes. Moreover, it gives a new sensitivity to the construction of space and the conception of scales [25].

Already in 2010, Andrew Jones and James T. Murphy reflected on the role of practice theory within economic geography [26] and offered a frame of operationalisation [27]. They define practices as 'regularised or stabilised social actions through which economic agents organise or coordinate production, marketing, service provision, exchange and/or innovation activities' [26, S. 302–304]. Furthermore, they argue that orientation on practice complements the research on economic action, considering that 'the social relations and interactions linking economic actors' [26, S. 303] are central in the shaping of 'the nature of economies, industries, and regional development processes [26, S. 303]. Consequently, Jones and Murphy provide a retroductive approach for practice-oriented research in two phases. First, the practice under study needs to be conceptualised by characteristics and constituting factors. Second, the researcher empirically studies context-related factors impacting the social actions (relations and interactions) and the socio-economic outcomes of the practice (see Fig. 1).

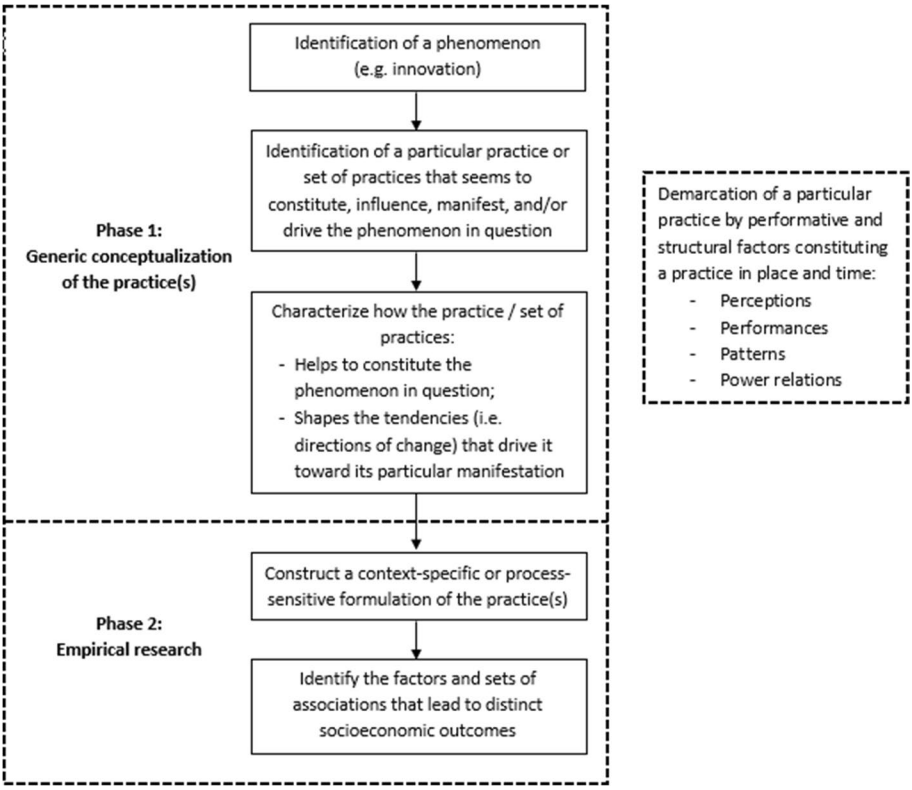

Fig. 1 Retroductive approach to the study of practice after Jones and Murphy [27]

Jones and Murphy's work resonated with the scientific community for claiming that a 'practice-oriented shift' had occurred in economic geography [28]. In this sense, following the authors' approach of conceptualising the circular economy in Luxembourg as a phenomenon implies identifying and characterising a set of practices that constitute, influence, and drive circularity. Identifying these practices follows a framework developed to guide empirical research on circular business practices [10] based on the three dimensions of practice: sayings, doings, and materiality [29]. In a further adaptation of the framework to the building industry, partial aspects were revised [30], which in turn led to the following ontology for the present study:

- Sayings: How stakeholders present circular construction practices in Luxembourg orally and in written documents.
- Doings: How standardised processes, procedures, and routines foster circular construction practices in Luxembourg.
- Materiality: How physical infrastructure, tools, regulation, policy, and resource availability (e.g., workforce) impact circular construction practices in Luxembourg.

In fact, for almost two decades, many scientific contributions have used social practice theories and conceptualised the term (social) practice. However, although many definitions

Table 1 Overview of interviewees

	Luxembourg
Unstructured interviews with public and private spokespersons	25
Industry experts — industry organisations, researchers, and municipality experts	25
Semi-structured firm interviews	41
Architects	8
Contractors — lead contractors, sub-contractors, and renovation firms	13
Expert consultants — circular economy experts, engineering, and consultancy firms	12
Materials professionals — manufacturers, expert services, and materials experts	8
Total number of interviews	66

are available, what a practice is from a theoretical perspective, the demarcation of a practice in more practical terms (where one practice starts and finishes compared to another practice) and in a long-term perspective (origin and end of a social practice) remains nevertheless blurry. The article contributes to this discussion by providing empirical insights from studying circular construction practices in Luxembourg.

A Qualitative Approach toward Circular Practices

The work presented in this article follows a retroductive research design to study the socio-political implications and possibilities for shifting current production-consumption-use-waste practices in more depth. Retroduction characterises a research process that links an inductive evidence-based logic from an empirical study with theory (deduction) in a dynamic and iterative process [31]. It permits conceptualising a research approach explicitly informed by theory in the sense of prescribing a particular way of forming ideas and notions about the studied phenomenon [31], e.g., using a specific ontology and language. This article emphasises the description and analysis of construction practices to understand whether traditional linear practices in the construction sector are changing to circular practices. As described in "Operationalising the Study of Circular Practices in Construction," the literature that informed the theoretical embedment of the empirical study comes from works on the circular economy in building and applied social practice theories.

The research used different datasets to draw a picture of Luxembourg's circular economy and construction practices: unstructured and semi-structured interviews, press articles and governmental publications, and notetakings from local events. In 2017 and the following 2 years, the study team conducted twenty-five unstructured interviews with public and private spokespersons to discuss how to implement a circular economy in the country, e.g., with researchers, civil servants, (circular economy) consultants, and topical experts. These exchanges gave insights into Luxembourg's transition from a linear to a circular production and consumption system. Then, in 2018, professionals from the construction sector participated in forty-one semi-structured interviews, i.e., architects, consulting engineers, general constructors, producers of building materials, and specialised building firms (see Table 1). The semi-structured expert interviews covered six main themes, dealing with the definitions and understandings of circular construction practices, their cooperation with partners and knowledge-sharing strategy, and the trends they see for a circular economy in Luxembourg. Following Robyn Longhurst [32], the semi-structured interviews with the professionals were

conversational and relatively informal. The interviewers did not use the interview guide to read the questions aloud but to order and partially structure the conversation. Thus, the interviewee could respond openly in her or his words and address issues how they like best. The interviews took place in the language of convenience for the interviewee. Twelve interviews happened in French, ten in English, and forty-four in German. The interviewer recorded the interviews with all participants' informed consent and transcribed the audio shortly after the conversation. The analysis of transcripts and written notes befell in the original language using MAXQDA, a computer-assisted qualitative data management software, to code the transcripts and other written documents in a three-step approach. In the first step, the data were categorised by themes established after several readings inductively, e.g., material and waste, design, motivations and barriers, and future trends.

- Material and Waste — material management, waste prevention, and recycling practices in the company: description of practices, plans or considerations regarding materials, their management, and end of life. It also includes regulatory aspects that relate to the topic, e.g., use of secondary raw materials, handling of offcuts and waste in the production process, sorting or treatment of waste (including upcycling), waste prevention concepts, and resource-saving packaging concepts.
- Design — product and process design for a circular economy: description of the product, process, or service design practices for a circular economy. Plans or informal conversations at the corporate level about changing design processes or product lifecycles, e.g., design for recyclability/dismantling, building lifespan extension, collaborative or participatory design processes, building information modelling (BIM), and modular building concepts.
- Motivations and Barriers — enablers and hindrances for implementing circular practices: descriptions of difficulties to implement circular solutions within the company, the industry, and the region. Incentives for companies to engage with circular solutions. Business case studies of success or failure circular implementations.
- Future Trends — Future developments of the circular economy in Luxembourg and beyond: subjective projections of potential, desired, or disliked circular developments within the company, the industry, or the region. Description of scenarios of future socio-economic developments.

In the second step, subthemes were inductively established per topical code to structure the data into manageable content and to identify business priorities. The following Table 2 summarises the two levels for the beforehand mentioned codes, and "Circular construction practice(s) in Luxembourg" presents the results of the qualitative content analysis [33] to capture patterns of practices from the building industry in Luxembourg and understandings associated with each theme.

In the third step and a retroductive logic, the evidence-based categories were interwoven with theory-informed dimensions of a practice: sayings, doings, and materiality. This last step of coding enabled focusing the analysis on the practices and the level of engagement in implementing circularity in the building sector in Luxembourg (Table 3).

The research considered different data sets as one way to ensure rigour and to permit checking and establishing the findings' validity [34]. This approach from multiple perspectives provides a clearer understanding of the problem under research due to its diversified view [35, 36]. However, some challenges occurred in practising this multiperspective. By combining different datasets, the total volume of data increases and thus the resources

Table 2 Two-level coding of circular practices

1	Material and waste	How does the company work towards circular material management?
2nd level code	Sorting	Separate waste collection
	Reuse	Materials are reused or internally recycled
	Prevention	Avoidance of the use of unnecessary materials, waste prevention through optimised planning and procurement
	Strategy	Overall material management (separation, reuse, prevention)
	Other	Practices that do not fit the other categories
2	Motivations	What are the company's reasons for implementing circular economy practices?
2nd level code	Demand	Demand from customers who ask for circular solutions and are willing to pay a higher price (including public procurement)
	Society	Norms and values of the society, including the view of employees
	Subsidies	Tax or other regulatory incentives, e.g. tax benefits for electric cars, subsidies for solar panels
	Bonus	Financial incentives for improvements, e.g. increasing energy efficiency and using sustainable and circular materials
	Reputation	Participate in a lighthouse project with financial incentives or a partially subsidised research project
	Materials	Availability or price of materials, e.g. use of secondary raw materials to compensate for price fluctuations or availability of raw materials; use of alternative materials
	Other	Reasons that do not fit the other categories
3	Barriers	What barriers does the company see in implementing circular economy practices?
2nd level code	Laws	Laws and regulations that hinder the elaboration and implementation of circular economy practices
	Industry	Industry rules (norms, values) that hinder a circular economy (including blocking power relations)
	Company	Rules or activities of the company that hinder a circular economy (including risk-averse behaviour)
	Knowledge	Lack of knowledge about the possibilities of the circular economy, e.g. of new technologies or materials
	Costs	Additional costs arising from circular economy practices, e.g. costs for research and development, higher material costs, purchase of new machines
	Infrastructure	Lack of infrastructure that is necessary for a circular economy, e.g. a functioning supply chain
	Other	Barriers that do not fit the other categories
4	Design	Does the company work on circular design practices in collaboration with architects or other experts?

Table 2 (continued)

2nd level code	Beginner	No implemented circular design practices so far. However, some initial considerations have been made in this regard
	Intermediate	Scenarios for circular design practices have been drawn, and some initial changes or adjustments have already been implemented
	Expert	Circular design practices are implemented strategically or systematically, e.g. to extend the product life cycle
5	Future of the circular economy	How do interviewees see the future of the circular economy?
2nd level code	Problematic	There will be problems and obstacles in the implementation of the circular economy
	Promising	The concept of the circular economy has potential. Companies can take advantage of circular economy practices
	Convinced	The circular economy is the concept of the future. No other concept offers comparable advantages
	Other	Opinions that do not fit the other categories

Table 3 Retroductive code scheme

Practice dimension		Code	
Sayings	How stakeholders present circular construction practices in Luxembourg orally and in written documents	Future trends	Potential, desired, or disliked circular developments within the company, the industry, or the region
Doings	How standardised processes, procedures, and routines foster circular construction practices in Luxembourg	Materials and waste	Material management and end-of-life, waste prevention and recycling practices
		Design	Product, process, or service design practices for a circular economy
Materiality	How physical infrastructure, tools, regulation, policy, and resource availability (e.g. workforce) impact circular construction practices in Luxembourg	Motivations and barriers	Structural and infrastructural enablers and hindrances for implementing circular practices

necessary to analyse them. Besides, the degree of precision varies in data recording [35]. The unstructured interviews only exist on the level of notes taken during the conversation; the semi-interviews with the professionals are available on two levels of documentation, audio recording, and transcriptions. Nevertheless, by applying the same analytical framework to the different datasets, general conclusions about circular practices in construction in Luxembourg could be drawn, as the following sections present.

Circular Construction Practice(s) in Luxembourg

Today, the Grand Duchy of Luxembourg is exemplary for a service economy. Luxembourg advanced to an international financial centre through different policy implementations since the 1960s, e.g., measures to encourage external investment. The country has one of the highest per capita gross domestic product (GDP) in the world, after Monaco and Liechtenstein, due to the economic concentration of the financial sector [37]. On the other hand, it is one of the most expensive countries in the European Union (EU), with substantial living costs due to rents and price levels for consumer goods and services above the average [38]. In the 2018 Eurobarometer edition, housing arises as 58% of the primary concern in Luxembourg [39] and let the current government consider affordable housing one of the country's biggest challenges. Researchers from the University of Luxembourg consider Luxembourg's mobility and housing crisis due to a political laisser-faire attitude regarding the country's significant economic and demographic growth [40]. The government's 'smart, sustainable, and inclusive growth' agenda [41] does not generate qualitative growth decoupled from resource consumption and social inequality. Luxembourg's per capita ecological footprint of 12.9 global hectares is one of the highest in the world [42] due to the carbon dioxide emissions related to the consumption and sales of fossil fuels [43]. However, the need for additional office and housing space results in substantial construction activities.

Consequently, the sector produces high amounts of construction and deconstruction waste (CDW) and excavation soils. Furthermore, as land is limited in Luxembourg and landfilling consumes the land, the selective deconstruction of buildings gains momentum, mainly because Luxembourg is poor in natural resources. Therefore, the recovery of materials enables circulation within national boundaries and reduces resource dependency.

The economic behaviour and development of companies in Luxembourg closely link to political guidance and incentives at the national level. The most recent frame sets the coalition agreement for the 5-year legislative period 2018–2023. In this document, the term 'circular economy' appears 39 times related to housing, public works, and sustainable development. This agreement continues the political openness of the last governmental program for the legislative period 2014–2018 to stimulate socio-economic developments in the country by sustainable concepts: '[T]he government will place particular emphasis on the issues of sustainable construction, sustainable mobility and the circular economy' [44]. Despite the urgent need for action, the National Housing Fund, a public housing development agency, engaged in 2016 in elaborating a master plan for the construction of 1000 new dwellings based on the principles of a circular economy. The building sector is not only in the policy focus on the circular economy agenda but significantly impacted by two studies commissioned by the government, i.e., a potential study for a circular economy in Luxembourg [45] and a third industrial revolution strategy for the country [46]. Since 2010, the energy efficiency of buildings has been on target as well and approached with a technology-driven agenda promoting sustainable construction through technical innovation [47].

The fundamental objective of a circular economy is to reduce the consumption of natural resources (e.g. fossil fuels, soil, water, and minerals) within a system (e.g., a national economy) through optimised management of the energy and material flows. 'The central idea is to close material cycles, to reduce the use of materials, and to reuse or recycle products and materials, to improve the quality of life through resource efficiency.' [48, p. 5943]. In a circular economy, the premises are to preserve the value of products, materials and resources for as long as possible and reduce or (ideally) even avoid waste altogether. By definition, the transition to a circular economy requires radical and significant changes in design, production, distribution, consumption, and use to eliminate the need to treat products as waste.

How companies perceive a political leitmotif largely depends on the actors of the concerned economic structure. The article deals with perspectives from the building industry in Luxembourg. It focuses on the sectoral handling of the political leitmotif concerning the circular management of materials and construction design processes in the past, present, and future.

Design Concepts and Materials

Several scientific articles discuss the definition of a circular economy because, in society, the concept still resonates little despite its political popularity [49–52]. For example, in Luxembourg, discussions about the circular economy were vivid in various arenas in the last decade but were only sometimes public. Consequently, the policy interest is high in gaining insights into the corporate stakeholders' understanding and interpretation of the circular economy concept.

In this study, most of the stakeholders in the building industry in Luxembourg were able to share their understanding of the circular economy, and the circular practices envisioned, discussed, and implemented at the corporate level. However, the data reflect the inconsistent reception of the term 'circular economy' in literature and the media: 'There are certainly as many different definitions of the concept as there are respondents', pointed out an architect (interview 29).

Often the term circular economy serves as a new buzzword for 'recycling', based on the German connotation of a 'Kreislaufwirtschaft'. In this sense, a 'beginner' company in circularity envisions and implements at the corporate level at first circular material management practices. In Luxembourg, for over 35 years, the SuperDrecksKëscht (SDK) has offered services in waste management to companies, such as support with the development of waste management plans, the installation of waste containers, or the disposal of hazardous substances. Many of the services offered by the SDK are free of charge for the companies, as different public entities subsidise them, i.e., the Ministry of the Environment, Climate and Sustainable Development, the Chamber of Skilled Trades and Crafts, and the Chamber of Commerce. In 2018, over 3200 companies in Luxembourg held the SDK waste management label. The companies see the opportunity to comply with the waste legislation in cooperation with the SDK and simultaneously improve their environmental performance. Central materials collection parks are best practices on construction sites because they bring cleanliness and orderliness. Such a collection park is also the basis for reuse concepts like the selective dismantling of buildings.

> […] we have noticed that if we collect waste selectively, it will be cheaper. Sorted waste can be sold if necessary […]. You cannot reuse [the material] again, but still. If you separate [the material], it's cheaper for you because the waste company can sell it directly again […].(interview 24).

The return of materials and products to the manufacturer or specialised waste disposal companies — the so-called re-consumption — can build on different systems. Take-back systems based on the selective collection have already existed for a long time in Luxembourg for various product groups, such as batteries, packaging, paints, and other household hazardous wastes. The reuse of materials in the building sector focuses on two main flows, asphalt/concrete, and wood, as the following sections develop.

Asphalt and Concrete

In the building industry, the reuse of materials — such as asphalt or construction and demolition waste — is a much-discussed topic, especially in road construction or infrastructure construction projects:

> What we have been doing quite a lot in Luxembourg for a long time is [the] recycling of asphalt. It means asphalt is removed from a road or milled out, heated, and mixed at a certain percentage with the new asphalt. This percentage […] is high, but we do not yet dare to allow recycling for various materials because we have to rely on an exceptional quality of bitumen. (interview 21).

In substructures of roads, the reuse of inert waste, such as construction rubble from demolition works, is widely spread. This downcycling signifies a quality loss of the material compared to the first use. In Luxembourg, the national offer typically meets the demand for crushed construction rubble. Only large-scale construction projects experienced supply shortages in the past, e.g., the extension of the runway at Findel Airport and the construction of terminal A, inaugurated in 2008. One of the main techniques applied in road rehabilitation at the national level is cold recycling in situ. The removed material is processed on-site and immediately reinstalled, which saves transport trips and shortens construction time. Cold recycling became interesting for Luxembourg since the landfilled blast furnace slags from steel production used in road works in recent decades are no longer available. In 1996, the national steel production converted to electric steel, and with the decommissioning of the last active blast furnace in 1997, the production and landfilling of blast furnace slags ended. Blast furnace slags have in Luxembourg a long tradition as cement substitutes in concretes and concrete blocks. Such waste materials and by-products from the steel industry, slags, and ashes, usually do not meet the quality requirements in a circular economy. Therefore, one of the future challenges at the national level will be how to deal with slag-cement concretes in a circular economy when these materials occur in deconstruction projects.

Another field of research in Luxembourg that attracted the attention of companies and university are aggregates made of secondary raw materials for use in concretes and precast concrete elements. The focus of current discussions is on the maximum percentage of permitted recycled aggregates in concretes; science and the public sector represent different positions in this regard:

> According to the standard, you can introduce up to five per cent of foreign materials into the concrete. That's five per cent recycling—that's all it takes. As soon as we want more, we must develop a new regulation. We are also in the process of revising the concrete standard. […] There, we intend to set a small accent [on recycled concrete]. […] I think I'll probably have to discuss this with [Person X] a bit. Because [Person X] wants to go further with the percentages. You can do that in a research project; I wouldn't do it in a bridge construction work right away. (interview 21).

Recycled aggregates for concrete and concrete products need to be accredited, which generates additional costs. These extra charges constitute barriers to why manufacturers hesitate to use recycled concrete. Besides, the companies argue that the composition of construction rubble bought on the waste market is generally unknown and therefore does not constitute a high-quality secondary raw material. Currently, there is no market for construction and demolition waste in Luxembourg, which is why the Administration of the Environment, Climate and Sustainable Development works with other stakeholders on new solutions. One of the first outcomes is a toolkit for material inventories for building dismantling with guidelines on how to specify quality criteria for building rubble.[1]

Wood

Wood plays a unique role in a circular economy. 'There is no material that is better suited for the circular economy than wood.', said a civil servant (interview 58), because the carbon footprint of wood is neutral considering the entire lifecycle. In addition, wood is usable or reusable in various ways, and it can be combined with different circular concepts, such as lightweight construction, modular construction, and selective dismantling. The industry in Luxembourg makes considerable efforts to use the wood in cascades:

> Our wish is to be able to process about half [of our return products] as recycled wood [into new products]. […] At the same time, we decided to burn the other half [of the return products] and use the energy [on site] in cascades. (interview 27).

In buildings, wood is a traditional material, but in Luxembourg, private owners have little trust in this raw material and prefer to invest in real estate from stone or concrete. So far, architects have only observed increasing awareness of healthy buildings with sustainable materials from renewable sources. As a result, more and more healthy wood buildings are rising, and many construction companies are expanding their offer to timber construction. Nevertheless, wood experts endorse the trend with caution because missing knowledge while dealing with wood can lead to severe defects in the building and harm the public opinion on timber in construction. They hope that the Luxembourgish construction industry gains experience with wood, for example, in the context of public construction projects, which can then serve as showcase projects and raise awareness for regional craft techniques that got lost:

> This is a small project: a small school building with two classrooms. A tiny investment project that was to be built with regional beech wood. The wood was also felled in the forests of [the commune]. […] according to old traditions, […] the wood was cut and dried according to the moon phase and brought back to Luxembourg. Unfortunately, no more sawmills in Luxembourg can dry and saw this hardwood. Twenty or thirty years ago, there were still quite a few [sawmills]. They are all extinct because all wood goes to China to build cheap furniture. (interview 35).

In the end, municipal elections took place, and the new board of council members decided to build the school elsewhere. Consequently, the school building in beech wood did not materialise. Other researchers state similar barriers due to a lack of cooperation between policymakers and industry [53] and thus highlight the importance of public–private partnerships in developing and implementing circular solutions, as highlighted in the following sections.

[1] The information about the construction/deconstruction waste inventory and the deconstruction guideline is available in French on the following website: https://environnement.public.lu/fr/offall-ressourcen/types-de-dechets/dechets-construction-demolition-dcd.

Materials Certification and Digitisation

More advanced companies in circular thinking have already developed a corporate roadmap for circular materials management, but they have yet to implement process adaptations. In this sense, some stakeholders of the building industry in Luxembourg explicitly demark the circular economy from waste management. 'When I talk about material cycling, I'm not talking about recycling,' said an industrial employee (interview 61). However, Luxembourg's circular material and resource management closely link with the waste management debate. The legislation also combines both terms, and the government published 2018 the new 'National Waste and Resource Management Plan' (NWRP) that lists measures to ensure the reuse, recycling, recovery, and disposal of waste in the most environmentally friendly conditions [54].

Some experts postulate that more than the recyclability of a material as a single indicator for selection is needed and that the entire life cycle of a product should be considered: production, use, and disposal. In order to evaluate and compare comprehensive material information, reliable data have to be accessible through databases such as the German database for ecological building materials WECOBIS.[2] Certification schemes for buildings and construction projects, such as the Luxembourg LENOZ system, can also help select materials. LENOZ works with Environmental Product Declarations (EPDs) for construction products commissioned by manufacturers, established by experts in the field, reviewed by independent bodies and then certified with the international standard ISO 14025. An EPD contains detailed product description and life cycle assessment data, such as the environmental impact of manufacturing, the supply chain, and the product's end-of-life. Some companies in Luxembourg have already taken this path and provide EPDs for selected products, including manufacturers in the cement and plastics industries. Some stakeholders in Luxembourg see EPDs and green building certification schemes as effective ways to sensitise the construction industry to 'life cycle thinking'.[3] The selection of building materials is critical in a green building certification. The products' technical qualities and full life cycle impacts are considered in this case. Other stakeholders see in EPDs and green building schemes as a limitation to innovation as these centralised systems limit the use of alternative materials without certified documentation. Production data are unavailable in lifecycle inventories due to a lack of data for new materials from natural fibres such as straw or elephant grass (miscanthus). Furthermore, the certification of material under ISO 14025 or the Cradle-to-Cradle (C2C) scheme is resource-intensive and consequently rarely affordable for innovative start-ups with niche products. In addition, the certification procedure takes some time and thus only meets long-time return-on-investments. Green building projects with miscanthus or straw insulation are, therefore, among the exceptions in Luxembourg.

Another point of interest for the circular economy experts in Luxembourg is the tracking of building materials. For the realisation phase of green buildings, standardised procedures and tools to check that the delivered materials correspond to the planning documents need to be developed. On construction sites, tracing the materials supply chains remains challenging as, for instance, large manufacturers fabricate the same products at different locations. The life cycle impacts of the materials supply chains in the

[2] WECOBIS is the ecological building material information system of the German Federal Ministry of the Interior and Community in cooperation with the Bavarian Chamber of Architects. URL: www.wecobis.de

[3] Life cycle thinking embraces impacts 'from the cradle to the grave' on the planet and people of a consumer product, but also a building, i.e., from the extraction of raw materials to the return of materials into the (technical) cycle.

precertification documents of a building certification often need to be crosschecked with the actual production and transport stages of the materials supplied to the construction site. If the building certification includes the material transport and the resulting impacts, a review of the place of manufacture must ensure that the planning and execution are in line. The digital tracing of the materials supply chain is one of the currently discussed topics by experts on building circularity in Luxembourg. These traceability considerations directly connect with the topic of the materials passport for buildings. The materials passport inventories all the materials present in a building to serve as a material bank in the future. Understanding buildings as material banks, i.e., temporary storage sites of materials, products, and components, intends to facilitate dismantling and increase economic efficiency. At the same time, material bank buildings reduce the country's dependence on resources.

In the highly decentralised construction industry, assembling a building's components inventory is challenging because the information transfer between the planning and execution phases often malfunctions. The stakeholders in Luxembourg consider closing these data transfer losses with systematic building data modelling (BIM) coupled with the use of material lifecycle inventory databases.

The Status Quo

The empirical study in the building industry in Luxembourg reveals that the material and resource discussion in the context of the circular economy still connects with the fundamental concepts of waste management. Legislation in Luxembourg combines both terms and speaks of 'waste and resource management' in the latest waste directive published in 2018 [54]. Contrary to the waste hierarchy, the circular economy concept only partially considers the disposal of materials by referring to the return of materials to the biological or technical cycles after use. Critics of this idealised approach from Luxembourg argue that the circular economy blends out material ageing and deterioration and losses caused by low return rates due to low collection rates. Summarising the empirical study of circular practices in Luxembourg, the stakeholders from the building industry highlighted three areas of intervention to improve the value-creation potential in a circular economy:

- Recognise the importance of the pre-project phase and emphasise the definition of project objectives and scope to prioritise circular materials;
- Design and plan buildings that are demountable and that can serve as material banks;
- Centralise information and data on the origin and composition of materials (e.g., in a material database).

Business Priorities

Many stakeholders from the building industry in Luxembourg have dealt intensively with concepts that offer alternatives to the linear production-consumption-use-waste scenario. Some companies have already introduced practices that align with the circular economy concept. The national debate focuses on materials, design concepts, and digitisation. The thematic overlaps highlight the complexity of the circular economy and visualise the need for an interdisciplinary approach to implementation (see Fig. 2):

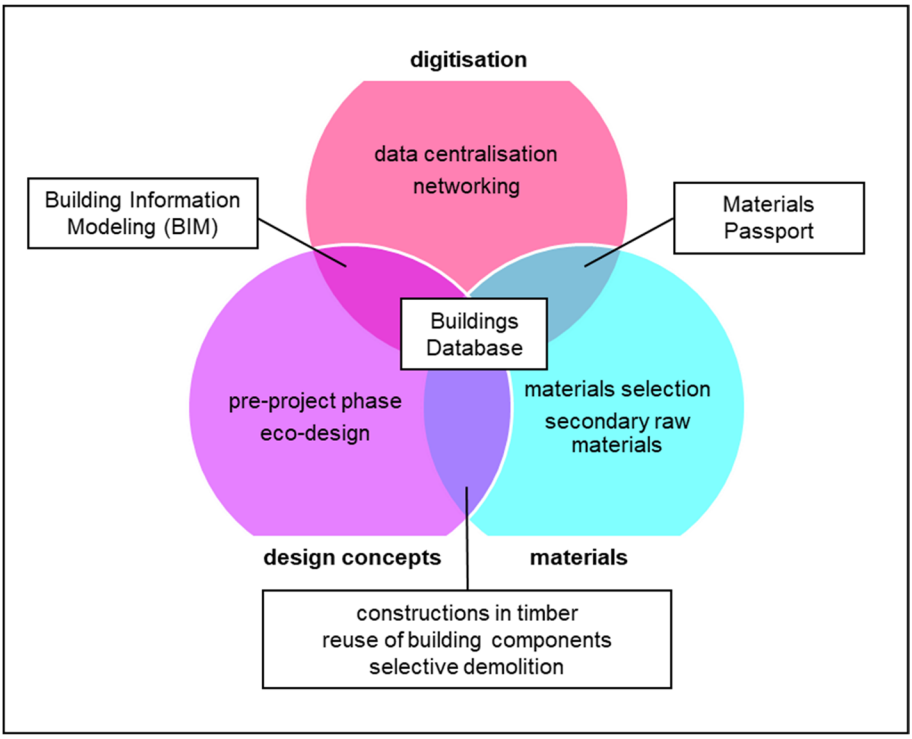

Fig. 2 Circular economy priorities in Luxembourg

- Design Concepts and Materials: The choice of materials significantly influences the reuse of building components and the selective demolition of buildings. Constructing in timber is a new trend for circular buildings in Luxembourg.
- Materials and Digitisation: The materials passport represents the digitised inventory of a building and includes, for example, relevant information about the building materials and components.
- Digitisation and Design Concepts: Building information modeling (BIM) is a digital footprint of a building and enables the project team (i.e. architects and engineers) to work on the same model through interfaces.
- Central Intersection: The buildings database collects information on materials and components of the national building stock and contains all the necessary data for their reuse (buildings as material banks).

Professionals from the building sector in Luxembourg have a good understanding and knowledge of the concept of a circular economy. Since the early 2000 years, the building sector has concentrated in compliance with developments in national and EU policy on sustainable building designs, lifecycle perspectives, and energy efficiency based on technological solutions [45, 55], in a logic of ecological modernisation [47, 56]. Hjaltadóttir and Hild [57] showed that the circular construction in Luxembourg closely links with the political agenda toward energy performance [58], sustainable development [59], and smart growth [60], as the following case highlights.

The Circular Hotspot Wiltz

So far, the political vision of a circular economy in Luxembourg materialises in the Circular Hotspot Wiltz, a town in the northern part of Luxembourg. The town of Wiltz situates 60 km from the capital and 10 km and 25 km from Belgium and Germany. The Circular Hotspot Wiltz aims to become not only a national flagship project but also intends to play a central and pivotal role in the cross-border region for the circular economy by integrating circular principles into spatial development. Wiltz became a local hotspot by official announcement through the Ministry of the Economy in October 2015, thanks to ongoing or panned local pilot projects. The overall 2015 program of the Circular Hotspot Wiltz included [61]:

- the reconversion of industrial sites alongside the river Wiltz into new residential projects;
- the construction of an apartment house with six units under circular construction premises;
- the integration of circular economy models in the business park named 'Salzbaach';
- the opening of a repair café;
- the opening of a fab lab; and
- the elaboration of a circular economy training for design students.

The first implementation of circular principles in a large construction project in Luxembourg happened in the masterplan development for one of the new residential areas on a reconverted industrial site alongside the river Wiltz. The 'Living with the river Wiltz' masterplan covers an area of 25.5 ha and foresees about 1000 new dwellings. The builder is the National Housing Fund, which aims to provide affordable housing in Luxembourg. For the elaboration of the master plan, an inter-ministerial group of more than fifty representatives from nineteen administrations [62] and six professional organisations incorporating an urban project management group [63] was set up in 2016. After a year of work, the group presented the masterplan with planning principles around four axes [62]:

1. A Social and Solidary Circular Economy: sharing economy, participatory approaches, citizen information;
2. Circular Spatial Planning: urban planning and building design/materials passport, free space planning, mobility, water management, remediation;
3. Circular Resource Management: waste management, material parks on construction sites, lifecycle approach;
4. Green Energy Supply: solar energy, power storage, renewable heat.

From a procedural point of view, the master plan is not a binding document in Luxembourg. Legally binding specifications must be determined in partial development plans (PAP). So far, only one PAP grounds on the'Living with the river Wiltz' masterplan, the so-called 'PAP Geetz – Quartier 2', was published in February 2018. This document speaks explicitly in article 10 about the circular use of materials: 'The choice of materials must be part of an ecological approach and must follow a logic of the circular economy.' [64, p. 7] In quantitative terms, the PAP prescribes that 10% of the materials used in buildings must comply with circular economy requirements, e.g., retaining walls in green spaces and playgrounds from natural stones of regional origin. Other circular economy design principles in the PAP are as follows [64]:

- Collective Facilities: bicycle parking and storage solutions, electric car charging points, and data storage facilities;

- A multifunctional community building with a community garden;
- Photovoltaic and solar thermal installations on roofs and façades;
- Energy-efficient buildings (minimum: energy class A);
- Open ditches for rainwater drainage;
- A majority of affordable housing.

Public circular construction projects and other pilot projects, such as the hotspot Wiltz, are important for stakeholders in Luxembourg to gain experience and exchange ideas. The scientific literature considers demonstration projects as political instruments to support learning processes and disseminate new technologies. The projects are often about niche solutions and best practice examples that focus on technology and less on its institutional embedding and potential to support social change [65, p. 639]. Some authors argue that demonstration projects represent values change triggered by complex social and economic value creation processes and therefore involve politics as an 'actor of change' [66, p. 625]. In Luxembourg, different studies recognise the importance of implementation projects for driving change processes in the field of sustainable construction [47], energy transition [67, 68], and water management [69]. However, an investigation of the impact of implementation projects for a transition to the circular economy at the national level only exists in China [70]. Research on the pilot projects in Luxembourg mentioned in this article still needs to follow, confirming that scientific papers on the circular economy discuss the concept theoretically and conceptually rather than implementations [71].

Discussion and Conclusions: Drivers are Governmental and Path-Dependent

This article views the circular economy in Luxembourg using the retroductive approach to the study of (social) practices suggested by Jones and Murphy [27]. The analysis highlights that in Luxembourg, the circular economy is, first of all, a political vision initiated in 2013/2014 by the government and since then continuously promoted by public authorities, e.g., through the pilot projects in the circular hotspot municipality Wiltz. Furthermore, several documents manifest the political will to transition towards a circular economy: the political programs of the legislative periods 2014–2018 and 2018–2023, the coalition agreement for the election period 2018–2023, and the National Reform Programme [41, 44, 72, 73]. The implementation examples show, however, that the circular economy in Luxembourg closely links with the building sector, enforced by an active policy focus on sustainable resource management at national and European levels over the last decade [57].

Standardised processes that foster a circular economy in Luxembourg mainly concern building and urban development projects. So far, operationalisations concentrate on the hotspot municipality Wiltz, as declared by the Luxembourg Ministry of Economy in 2015. One of the pilot initiatives in Wiltz, the masterplan for the new urban development 'Living with the river Wiltz', integrates circular planning criteria for materials, water management, energy, and social cohesion. This masterplan development brought together decision-makers from public authorities, and the planning team comprised of architects, urban planners, and engineers. This integrative planning approach in such an early development project stage considers a critical success factor in sustainable construction and the circular economy. Over fifty people worked on the master plan and contributed to its

finalisation in 2016. However, implementations in Wiltz witness the importance of the state in all the projects. Only with the commitment of local and national authorities (i.e., municipality of Wiltz, Housing Fund, Ministry of the Economy) the concept of a circular economy in Luxembourg would anchor in any standardisation.

The materiality of a circular economy in Luxembourg cumulates in the hotspot Wiltz. The municipality of Wiltz signed a charter for a circular economy in 2018 [74], and the state-financed Agency for Research and Innovation borrowed the municipality a workforce for implementing the program of the Circular Hotspot Wiltz. However, more and more tools for supporting circularity arise at the national level. The most prominent example of operationalisation is LENOZ, the sustainability certification scheme for residential buildings developed by the Ministry of Housing. Since 2016, a LENOZ certificate has been mandatory to apply for funds to improve the energy efficiency of existing buildings.

The results presented in this article show that circular construction practices in Luxembourg target design criteria, materials selection, and digitisation. In this sense, the circular economy in Luxembourg can be conceptualised as a bundle of sustainable construction activities that traditionally spotlight materials, building design, and technologies. In 2006, the first 'Guideline for sustainable construction and renovation' in Luxembourg, grounded on scientific evidence, was published and subsequently updated in 2008/2009 and 2010 [75, 76]. This guideline provides design principles for sustainable buildings, including environmental impact indicators (e.g., greenhouse gas emissions, acidification potential, energy demand) for various construction materials. The guideline has no legal impact but is an established document in Luxembourg and uniquely referenced by public authorities. A kind of continuation of the guideline is the national certification scheme for housing (single houses and residential buildings) called LENOZ. LENOZ is an initiative of the Luxembourg Housing Ministry evaluating the performance of new or renovated dwellings concerning different criteria in line with sustainable construction, sustainability and the circular economy. A total of 143 criteria, subdivided into 37 categories, evaluates the sustainability level of a building in four classes [77]. The criteria affecting the result of a new dwelling the most are energy costs (11%), environmental impacts of materials (11%), and land use (7%). Criteria considered as 'typical circular' value less, e.g., recyclability/demountability of the building (3%), health/indoor air quality (5%), or initial operation/documentation of technical installations (3%).[4]

Digitisation in construction is another popular topic in Luxembourg when professionals talk about current and future trends in the field. Digitisation covers different aspects, including BIM, the internet of things, and smart solutions (e.g., for mobility, homes, and communication). In 2016, the National Agency for Research and Innovation published 'A smart day', a promotional video for a futuristic life in Luxembourg that is smart, connected, and driven by technology [78]. More than 6 min in length, the film advertises Luxembourg as a testbed for innovative technologies to attract investors and start-ups.

Critical voices to the technology-driven economic development plans for Luxembourg question the durability of the strategy within the planet's resource limits and the well-being of people [10, 79, 80]. However, the post-development debate that claims, among other things, qualitative growth (well-being), inclusive solutions (more diversity and more people involved), and sufficiency (less consumption) remain underrepresented in Luxembourg. As many authors claim, the sustainability of the circular economy from a systems perspective and circular practices need to be evaluated and monitored for their contribution to sustainable development [81–84].

[4] The percentages refer to the LENOZ version of 2016 (tool version: 1.31.0 and handbook version: 53).

Appendix

Table 4 Overview of the 66 interviews

No	1	2	3	Interviewee			
				4	5	6	7
1	UI	03–2017	E	Regional development (public)	Manager	1	Industry expert
2	UI	07–2017	E	Innovation agency (public)	Manager	1	Industry expert
3	UI	07–2017 and 02–2018	D	Consultancy	CE Expert	1	Industry expert
4	UI	09–2017	D	Research	Professor	1	Industry expert
5	UI	09–2017	E	Research	Professor	1	Industry expert
6	UI	09–2017 and 02–2018	D	Research	Professor	1	Industry expert
7	UI	10–2017	D	Research	Researcher	1	Industry expert
8	UI	10–2017	D	Research	Manager	1	Industry expert
9	UI	10–2017	E	Innovation agency (public)	Manager	1	Industry expert
10	UI	11–2017	E	Innovation agency (public)	Manager	1	Industry expert
11	UI	11–2017	E	Public entity	Civil servant	1	Industry expert
12	UI	11–2017	E	Public entity	Civil servant	5	Industry expert
13	UI	11–2017	E	Public entity	Civil servant	2	Industry expert
14	UI	12–2017	E	Research	Researcher	1	Industry expert
15	UI	12–2017	F	Regional development (private)	Manager	1	Industry expert
16	UI	01–2018	F	Research	Researcher	3	Industry expert
17	SI	02–2018	D	Structural engineering	Quality Manager	1	Contractor
18	SI	02–2018	D	Manufacturer	Consultant	1	Materials professional
19	SI	02–2018	D	Architecture office	Architect	1	Architect
20	SI	03–2018	D	Manufacturer	Manager	1	Materials professional
21	SI	03–2018	D	Public entity	Civil servant	1	Materials professional
22	SI	03–2018	D	Architecture office	Architect	1	Architect
23	SI	03–2018	D	Manufacturer	Manager	1	Materials professional
24	SI	03–2018	D	Engineering office	Manager	1	Expert consultants
25	SI	03–2018	D	Architecture office	Architect	1	Architect
26	SI	04–2018	D	Structural engineering	Consultant	1	Contractor
27	SI	04–2018	D	Manufacturer	Manager	1	Materials professional
28	SI	05–2018	D	Subcontractor	Manager	1	Contractor
29	SI	05–2018	D	Architecture office	Architect	1	Architect
30	SI	05–2018	F	Education and training	Manager	1	Expert consultants
31	SI	05–2018	D	Consultancy	Architect	1	Architect
32	SI	05–2018	F	Engineering office	Manager	1	Expert consultants
33	SI	05–2018	D	Subcontractor	Manager	1	Contractor
34	SI	06–2018	D	Architecture office	Architect	1	Architect
35	SI	06–2018	D	Architecture office	Architect	1	Architect
36	SI	06–2018	D	Structural engineering	Manager	1	Contractor

Table 4 (continued)

No	1	2	3	Interviewee			
				4	5	6	7
37	SI	06–2018	D	Structural engineering	Manager	2	Contractor
38	SI	06–2018	D	Project management	Manager	1	Expert consultants
39	SI	07–2018	F	Manufacturer	Manager	1	Materials professional
40	SI	07–2018	D	Structural engineering	Manager	1	Contractor
41	SI	07–2018	D	Project management	Architect	1	Architect
42	SI	07–2018	D	Structural engineering	Manager	1	Contractor
43	SI	07–2018	F	Structural engineering	Manager	2	Contractor
44	SI	07–2018	F	Subcontractor	Manager	1	Contractor
45	SI	07–2018	D	Project management	Manager	1	Contractor
46	SI	09–2018	D	Project management	Manager	1	Contractor
47	SI	04–2018	F	Consultancy	Manager	1	Expert consultants
48	SI	05–2018	D	Transport company	Manager	2	Materials professional
49	SI	05–2018	E	Consultancy	Manager	3	Expert consultants
50	SI	05–2018	F	Consultancy	Manager	1	Expert consultants
51	SI	06–2018	D	Consultancy	Manager	1	Expert consultants
52	SI	06–2018	D	Consultancy	CE Expert	1	Expert consultants
53	SI	06–2018	D	Professional association	Consultant	1	Expert consultants
54	SI	06–2018	D	Professional association	Consultant	1	Expert consultants
55	SI	06–2018	F	Professional association	Manager	1	Expert consultants
56	SI	07–2018	D	Waste management	Manager	2	Materials professional
57	SI	07–2018	D	Industry	Manager	2	Contractor
58	UI	09–2019	D	Public entity	Civil servant	1	Industry expert
59	UI	10–2019	D	Public entity	Employee	2	Industry expert
60	UI	10–2019	D	Innovation agency (public)	Manager	1	Industry expert
61	UI	11–2019	F	Industry	Employee	1	Industry expert
62	UI	11–2019	D	Public entity	Civil servant	1	Industry expert
63	UI	11–2019	D	Transition movement	Member	1	Industry expert
64	UI	12–2019	D	Transition movement	Coordinator	1	Industry expert
65	UI	12–2019	D	Public entity	Civil servant	1	Industry expert
66	UI	12–2019	F	Public entity	Manager	2	Industry expert

1 = type of interview (UI = unstructured interview; SI = semi-structured interview); 2 = date of the interview; 3 = language of the interview (D = German, E = English, F = French); 4 = work area of the interviewee; 5 = position of interviewee; 6 = number of interviewees; 7 = interviewee category (cf. Table 1).

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Data availability Not applicable.

Declarations

Ethics Approval and Consent to Participate The questionnaire, consent form, and methodology for this study were approved by the Ethics Review Panel (ERP) of the University of Luxembourg (ethics approval number: ERP 17–023). Informed consent was obtained from all individual participants included in the study.

Consent for Publication Informed consent was obtained from all individual participants included in the study.

Competing Interests The authors declare no competing interests.

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