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COLLABORATIVE PLATFORMS SUPPORTING CIRCULARITY IN THE BUILT ENVIRONMENT. IDENTIFYING STRATEGIC ACTIONS AND REPLICABLE GOOD PRACTICES

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ABSTRACT

This contribution highlights the role that collaborative platforms can offer for the promotion of circularity in the construction sector, through the interaction between different stakeholders and, in particular, through the collection and promotion of good practices. In fact, the work reports the outcomes of stakeholder consultation experiences, developed within the Italian Circular Economy Stakeholder Platform, aimed at identifying the strategic areas and priority actions for the scale-up circular solutions to a large scale, and activities of collection, selection and analysis of good practices at different scales (products, buildings, tools) that exemplify the possibility of concretely implementing - in a highly replicable manner - the circular solutions, until now often considered experimental cases that are difficult to be repeated.

1. INTRODUCTION

The construction industry involves the production, maintenance and end-of-life management of a wide variety of infrastructure and buildings. From an economic point of view, the gross domestic product (GDP) of the construction industry enhances the growth of nations. Specifically, Suwal et al. (2019) stated that the construction industry contributes 6% to GDP globally. Although the construction industry positively impacts GDP, its activities have negative consequences for the environment, society, and the economy. Recent estimates reveal that the building and construction sector consumes about 40% of materials and produces roughly 35% of waste (Agyekum et al., 2024). Moreover, construction is responsible for 36% of energy consumption and 37% of energy-related CO2 emissions (UNEP, 2021).

Therefore, the construction industry is highly materials-intensive and significantly contributes to global solid waste generation. Furthermore, although policies have been developed at different levels to improve the sustainability of the sector, they do not focus entirely on a circular economy (Adams et al., 2017), but rather prioritize strategies to reduce operational energy consumption. Recently, much of the thinking on the circular economy has focused on short- and medium-term consumer products (Adams et al., 2017).

In fact, research and large-scale practical applications of circular economy in the built environment are still limited, both at the component/material level and at the building level (Adams et al., 2017). Moreover, a holistic perspective is necessary to assess the construction sector more broadly, ensuring genuine positive impacts in terms of reduced resource extraction and related climate-changing emissions (Baiani and Altamura, 2021).

The aforementioned data have prompted the construction industry to pursue changes in its practices and redefine concepts such as Circular Construction to facilitate the transition to a circular economy. Circular Construction involves applying circular economy principles to the built environment with a systemic vision that extends beyond 'green buildings,' which focus on technology and environmental concerns, or 'sustainable buildings,' which also address economic and social dimensions. Circular buildings prioritize the support and behavior of stakeholders - e.g. government, customers, suppliers, builders (Pomponi and Moncaster, 2017). These buildings are designed to embrace circular principles and close resource cycles at different spatial and temporal levels. This reflects the complexity and dynamic nature of the circular economy in construction, requiring consideration and integration of technical, social, economic, environmental, behavioral,

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spatial, and temporal aspects (Papastamoulis et al., 2021; Yu et al., 2022).

Thus, circular design and construction processes in the built environment necessitate a significant change in the approach of all actors involved and their supply chains. This process involves not only designers but also principals, contractors, and manufacturers. Additionally, there is an increasing need to train new professionals capable of implementing innovative circular business models, such as specialists in deconstruction and the sale of salvaged components (e.g., Restado, Rotor DC, Cyrkl).

In this process of change, multistakeholder platforms can play a key role by fostering the involvement and collaboration of different actors who, based on shared values, are willing to work together to enhance their knowledge and skills systems for collective progression. Consequently, the traditional triad known as the triple helix model of innovation — formed by university, industry, and government — has evolved. Over time, this model has been reinforced with new models of knowledge generation, incorporating media, shared culture, civil society, and the environment, thus evolving into the quintuple helix model of innovation (Carayannis & Campbell, 2010).

By adopting the theoretical framework proposed by the quintuple helix model, this paper demonstrates how collaborative platforms can foster cultural exchanges to fully contribute to resource efficiency and climate neutrality goals. These platforms can also serve as repositories of best practices that promote the scalability and replicability of innovations in the market.

2. INTERNATIONAL COLLABORATIVE PLATFORMS FOR CIRCULARITY IN THE CONSTRUCTION SECTOR

This section describes a selection of existing online collaborative platforms that can be traced back to the quintuple helix model by having a multiplicity of stakeholders belonging to the different domains as well as being 'archives' of good practices related to the built environment. Among the different existing platforms, the following is a non-exhaustive list involving European, national as well as cross-border platforms: the European Circular Economy Stakeholder Platform (ECESP) and the corresponding Italian national platform (ICESP); the Holland Circular Hotspot; the Circular Taiwan Network. These platforms have been selected in the research because they showcase good practices which are considered virtuous examples of innovation (at the product, process, but also organizational level) that can favour the transition towards a circular construction sector. The interdisciplinary approach of the selected platforms promotes and facilitates the mapping and exchange of good practices.

2.1 European Circular Economy Stakeholder Platform (ECESP)

The European Circular Economy Stakeholder Platform (ECESP) is a joint initiative of the European Commission and the European Economic and Social Committee that supports civil society organisations and public authorities accelerating the transition to a circular economy in Europe by promoting dialogue, knowledge sharing and exchange of best practices. As stated on its website (https://circulareconomy.europa.eu/platform/en) as a 'network of networks', ECESP provides a 'place' for stakeholders to come together to share and scale effective solutions and address specific challenges. The platform bridges existing local, regional and national initiatives and supports the implementation of the circular economy in multiple sectors. Stakeholder engagement is encouraged through thematic working groups (so-called Leadership Groups). In particular, the Leadership Group on the built environment has identified two main priorities: to support the integration of circularity aspects into existing (or upcoming) legislation; and to foster the standardisation of materials by promoting the introduction of digital passports for materials across the EU. The work of the leadership group and the ECESP platform database resulted in a first compilation of good practices related to the built environment (ECESP, 2021a).

2.2 Italian Circular Economy Stakeholder Platform (ICESP)

The Italian Circular Economy Stakeholder Platform (ICESP) is the Italian national mirror platform of ECESP. ICESP was created as a forum that brings together the initiatives, experiences, critical issues and prospects that Italy represents and has the potential to represent in Europe in a circular economy, promoting circularity also with specific actions. As declared in its website (https://www.icesp.it/), ICESP aims at: promoting the dissemination of knowledge; fostering dialogue and synergic relations among Italian actors; mapping Italian good practices; overcoming the fragmentation of initiatives at the national level; creating a permanent operational tool that can stimulate and facilitate cross-sectoral and inter-sectoral dialogue and interactions; promoting Italian excellence and 'the Italian way of doing circular economy', starting from traditional characteristics and related cultural, social and entrepreneurial models. The platform is open to all players in the circular economy sector (public administrations, firms, research organisations and civil society) and adopts an inclusive approach. Among the different working groups, the one on 'Sustainable and Circular Value Chains' includes a specific sub-group on 'Construction and Demolition', with the aim of developing position papers, collecting good practices in the market and organising webinars/seminars on specific topics related to the built environment. The work of the subgroup resulted in a first position paper that includes priorities to foster cycle closure in the built environment and an initial list of good practices related to the sector (Altamura et al., 2020).

2.3 Holland Circular Hotspot

The Holland Circular Hotspot is a private organization dedicated to expediting the global shift toward a circular economy. It achieves this by fostering connections among companies, knowledge institutes, and local authorities, facilitating international collaboration, and promoting knowledge exchange on the Dutch circular economy. It collabo-

rates with different partners on topics as diverse as textiles, plastics, circular cities, water and construction. In particular, the construction group explores how circular economy concepts can help address challenges in the sector, supporting the transition to a more sustainable construction sector. The work of the Holland Circular Hotspot resulted in a compilation of good practices related to the built environment in the Netherlands (Holland Circular Hotspot, 2022).

2.4 Circular Taiwan Network

The Circular Taiwan Network (CTN) is a non-profit organization dedicated to advancing the circular economy in Taiwan. Since its establishment in 2015, CTN has been actively communicating, supporting, and facilitating coordination among all sectors of society—including government, industries, universities, research institutes, civil society organizations, and media—to promote the transformation of Taiwanese industries and society. The platform's overarching vision is to integrate the principles of the circular economy into Taiwan's daily life and position Taiwan as a global leader in the circular economy movement. To achieve this, CTN engages institutions, industries, universities, research institutes, civil society organizations, media, and international entities through its "CoPartners Circular Partner Platform". The CTN also collects good practices that are organised by theme: Agribusiness and biomass, plastics, textiles, construction, transport, electronics and chemicals. More in detail, six areas of improvement have been identified to foster the transition to the circular economy of the construction sector: Extension of the life cycle of existing buildings together with energy efficiency; Planning for the recovery and reuse of new buildings; Establishment of an appropriate evaluation system for circularity in construction; Promotion of shared building materials through rental services; Improvement of materials through collaborative partnerships; Quantification and definition of targets for the management of the circularity of total resources in the construction industry. The work of the CTN resulted in a collection of local good practices related to the built environment (Circular Taiwan Network, 2024).

3. RESEARCH AIMS AND METHODOLOGY

The research originated within the activities of the ICESP Construction and Demolition sub Working Group (see Section 2.2) and was subsequently developed through the methodology described below. The research started from the Priorities for a circular recovery after the COVID Pandemic identified by the whole ICESP platform in 2020 in a dedicated document (ICESP, 2020). These priority areas of action were connected by the stakeholders of the different Working Groups to the three reference systems: Context (with relative priorities identified as Governance; Education, information and culture; Infrastructural system), Tools (with relative priorities identified as Economic tools; Regulatory tools; Assessment tools) and Actions (with relative priorities identified as Eco-design and circular consumption models; Market for by-products, recycled and recovered materials; Integrated planning and circular urban and territorial management).

Based on this framework, the research aimed to identify the primary strategic actions for advancing circularity within the national construction sector by consulting stakeholders participating in the ICESP Construction and Demolition sub Working Group. Figure 1 shows the results of this activity: the stakeholders in the Group were asked to reflect on the general priorities listed in the above mentioned document, shared by all the stakeholders of the ICESP plat-

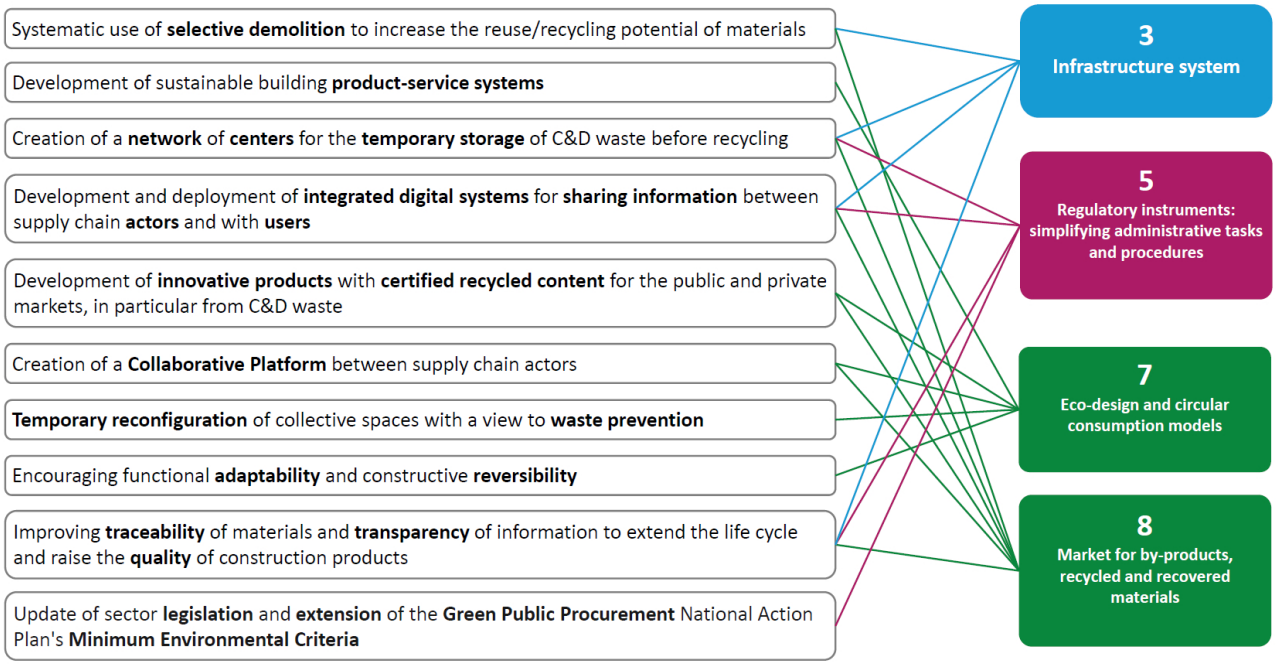

FIGURE 1: Links between the ICESP Priorities for a circular recovery after the COVID Pandemic, defined by the whole platform, and the ones identified by the C&D working group.

form, and to propose more specific priority actions – deriving and connected to the general ones - to be implemented in construction sector.

Subsequently, the research activity was further developed with the objective to uncover both national and international replicable good practices of various types and scales (including material, product, process, and building levels), able to exemplify the specific priorities identified by the Construction and Demolition sub Working Group. These examples were sourced from the database of good practices within the aforementioned platforms, as well as from the outcomes of stakeholders' engagement activities such as ECESP's EU Circular Talks (ECESP, 2021b).

The selected good practices serve to showcase the practical implementation of solutions that were previously perceived as experimental and challenging to be replicated. Adopting an exploratory qualitative approach grounded in the methodology of multiple case studies and participatory action research, the study analyzed several key Italian and international examples. These examples were then correlated with the strategic actions identified through the ICESP subgroup consultation, with the aim to select six exemplary good practices of different typologies, each embodying more than one of the priority strategic actions for the construction sector identified through stakeholders' consultation.

3.1 Outcomes of the stakeholder consultation on priorities for a circular construction sector

Among the priorities indicated by the stakeholders of the ICESP sub Working Group Construction and Demolition (Table 1), the first is the creation of a collaborative platform, which is to be understood as a cooperative or system for collaboration between companies operating with the same type of goods, such as the Italian CPR System for the circular management of packaging in the agro-food sector, to be applied within the recycled aggregates supply chain.

A key aspect for the sector involves enhancing material traceability and information transparency to extend the life cycle and enhance the quality of construction products. Faced with recent functional re-layouts aimed at adapting spaces to new requirements (e.g., distancing, separation), it becomes imperative to prioritize not only the flexibility and reversibility of construction systems but also the traceability of materials and increased transparency of information. Only in this way will it be possible to aim at extending the life cycle of construction materials/products and avoid the generation of waste.

Specifically, concerning materials within existing built heritage, it is crucial to establish connections among various stakeholders in the supply chain (such as professionals, demolition firms, and recycling ones) to ensure traceable data flow - from pre-demolition audits to recycled products certification - passing through the characterization of the waste. Additionally, it is vital to institute feedback mechanisms from recyclers to identify prevalent contaminating factors in specific areas and types of buildings (based on construction period and/or geographical location).

A strategic front for the construction sector also includes encouraging functional adaptability and constructive reversibility. The COVID emergency has forced the widespread re-organization of spaces, from hospitals to

TABLE 1: Grouping of priorities into strategic actions for circularity practices' scale-up.

Priorities indicated by ICESP C&D working group's stakeholders	Strategic actions for circularity practices' scale-up
Collaborative platform (innovation)	Creation of a collaborative platform
Improving and certifying the quality of C&D waste products	Improved traceability of materials and transparency of information to extend the life cycle and raise the quality of construction products
Material traceability and information transparency with a view to life cycle extension	
Temporary reconfiguration of collective spaces (offices, schools, health) and waste prevention.	Temporary reconfiguration of collective spaces (offices, schools, healthcare) and waste prevention
Functional adaptability and constructive reversibility	Encouraging functional adaptability and constructive reversibility
Promoting the adaptability of construction for the circular economy	
Development of Sustainable Product-Service Systems	Development of Sustainable Product-Service Systems
Creation of a network of widespread collection points for C&D waste	Creation of a network of centers for the temporary storage of C&D waste before recycling
Development of integrated systems for information sharing between actors in the supply chain.	Development and dissemination of integrated digital systems for sharing information between actors in the chain and with users
Development and dissemination of software aimed at supply chain actors and potential users	
Innovative materials produced with a high percentage of C&D waste	Development of innovative products with certified recycled content for the public and private markets, in particular from C&D waste
Development of products for the public and private markets with recycled content and certificates	
Use of recycled aggregates from C&D waste in cement production	
Selective demolition	Systematic introduction of selective dismantling to increase the recycling potential of the existing materials
Introducing selective demolition in a systematic way	
Selective demolition of buildings for improved recycling capacity of all materials present	
Systematic introduction of selective demolition	

houses, and has made it necessary to quickly set up temporary spaces. In order to avoid the increase in resource consumption and waste production linked to the adaptation, construction and dismantling processes of buildings, it is necessary to develop systems, products and process models that guarantee high reversibility within life cycle transformations, which are difficult to be predicted. For example, in interventions on the existing built heritage, it is necessary to favor design choices and intervention methods that favor the future receptivity of innovative building components. This aspect is linked to the temporary reconfiguration of collective spaces (offices, schools, healthcare facilities, etc.) through the design and creation of temporary configurations with a view to reversibility, reusability and transformability of products, building components and of buildings as a whole. In addition, it would be desirable to conduct a census by categories of all materials used in temporary situations in order to identify organisational models and supply chains for the selection/recovery/reuse/recycling of materials able to ensure an efficient use of resources.

The COVID emergency has also highlighted the need for alternative organisational and business models in the construction sector. Among these, the development of Sustainable Product-Service Systems is a promising scenario to provide customers with a sustainable result in terms of environmental load and resource utilisation, without transferring ownership.

Further priorities come from government policies. The introduction of significant incentives in the Italian 'Rilancio' Ministerial Decree (the so called 'Superbonus 110%' for buildings' energy retrofits) lead to an increase in the volume of C&D waste. Therefore, stakeholder proposed the creation of a widespread network of preliminary collection centres (e.g. at building material dealers' showrooms) to receive and temporarily store waste for subsequent recycling at duly authorised facilities. In addition, to ensure quality management of C&D waste from an environmental and technical point of view, the need for integrated digital systems for sharing information between the various stakeholders in the chain was highlighted, considering all stages of the life cycle, from demolition to waste treatment and reuse of materials. Digital tools are also needed to support operators in matching supply and demand. Hence, the development and dissemination of integrated digital systems for sharing information between supply chain actors and with users is seen as a priority.

Again, linked to government policies, given the extension of the obligation of the Italian Green Public Procurement Minimum Environmental Criteria for public buildings (Ministerial Decree) to private interventions under the Superbonus, it became a priority to develop new products with adequate recycled content and appropriate environmental certification, particularly for thermal insulation. In fact, to allow the use of products compliant to the mandatory criteria, which foresee minimum recycled content thresholds, the development of innovative certified products, providing users with the necessary traceability and performance information, plays a key role. For example, in the cement supply chain, it becomes a priority to experiment the use of recycled aggregates from inert waste, currently used in cold cycles (concrete mixes), to partially replace the natural raw materials (limestone, clay, etc.) needed to make the so-called raw meal which, once fired in cement kilns, is turned into clinker (the main component of cement).

Finally, the systematic introduction of selective demolition would increase the recycling potential of materials in the built environment by ensuring quality circular processes, of which recycled aggregates for concrete are an example. Although a progressive increase in the attention of construction companies towards C&D waste sorting processes can be observed today in Italy, bureaucratic, economic and organisational barriers remain to a significant extension of selective demolition at national level. In order to overcome these barriers, an in-depth analysis of selective demolition techniques and related costs is needed, with reference to the reuse/recycling potential of the different types of materials (aggregates, plasterboard, iron, wood, plastics, etc.) and components, with a view to strengthening the associated recovery value chains. In parallel, it is indispensable to promote an architectural/technological design that, from a life cycle perspective, envisages the separability of components at the end of their useful life. Only through proper design, to be carried out prior to construction/demolition activities, can materials of a quality suitable for recovery be obtained.

4. RESULTS AND DISCUSSION

The six good practices presented here have been drawn and selected from the pool of those collected in the ICESP, ECESP and Taiwan Circular Network platforms. They were therefore gathered with a bottom-up approach by the stakeholders involved in the collaborative platforms but subjected to the scrutiny of the respective good practice evaluation committees, with reference to criteria such as levels of innovativeness and replicability. As anticipated, the six good practices exemplifying multiple priority actions identified by the ICESP's stakeholders are referred to different levels/scales: two at the building level (ZIN Project and Taitsugar Village), two at the product level (rice waste-based building products and concrete with certified recycled aggregates), two at the digital tool level (Madaster and Concular platform). The selection criteria considered in fact at the multiscalarity required by circularity in such a complex sector as construction and aimed at showing innovative products, building and neighboorhood design as well as digital tools supporting the development of both products and buildings. Moreover, the selected good practices are promoted by different actors involved in the abovementioned Platforms and representing various Countries (Belgium, Taiwan, Netherlands, Germany, Italy), in order to highlight some international excellence experiences in circular construction.

The following table (Table 2) shows the multiple links between selected the good practices and the strategic actions identified in the ICESP's stakeholders' consultation, the results of which were described in the previous section.

TABLE 2: Comparative chart of the selected six good practices in relation to the strategic actions collected in the ICESP C&D working group stakeholders' consultation.

Good practice	1	2	3	4	5	6
Scale	**Building/neighborhood**		**Product/material**		**Digital tool**	
Strategic reference actions	**ZIN Project**	**Taitsugar Village**	**Rice waste-based building products**	**Concrete with certified recycled aggregates**	**Madaster platform**	**Concular platform**
Creation of a collaborative platform	X				X	X
Improved traceability of materials and transparency of information to extend the life cycle and raise the quality of construction products	X	X	X	X	X	X
Temporary reconfiguration of collective spaces (offices, schools, healthcare) and waste prevention	X	X				
Encouraging functional adaptability and construction reversibility	X	X				
Development of Sustainable Product-Service Systems		X				
Creation of a network of centers for the temporary storage of C&D waste before recycling	X			X		
Development and dissemination of integrated digital systems for sharing information between supply chain actors and with users					X	X
Development of innovative products with certified recycled content for the public and private markets, in particular from C&D waste	X	X	X	X		
Systematic introduction of selective dismantling to increase the recycling potential of the materials present	X	X				

4.1 ZIN Project (Brussels, BE)

In 2018, a brand-new application of circularity principles was initiated in the renovation of two of the four towers of the World Trade Centre in Brussels in the ZIN project, currently under construction. The good practice was promoted in a stakeholder engagement activity organised by ENEA as part of ECESP (Circular Talk, 2021), and was illustrated by Drees and Sommer, a consultancy firm that focuses on the implementation of the Cradle to Cradle design approaches and certification systems (EPEA).

The development of a materials inventory on both buildings enabled the use of different strategies to prevent C&D waste and diverted it from landfill through reuse, recycling and upcycling, and the certification of materials in cooperation with different stakeholders, adopting the 'Building as Material Bank' approach (Figure 2).

This ensured that 95 per cent of existing materials were kept in place, reused or recycled, while 97 per cent of new materials are Cradle to Cradle certified or equivalent, including concrete with onsite produced recycled aggregates (Figure 3).

The whole process was supported by EPEA and Drees and Sommer from the selective demolition of concrete, its on-site recycling, and the production of recycled aggregates to make Cradle to Cradle certified concrete to be reused in the deep tower retrofit project, which saw the introduction of a previously unforeseen functional mix.

Overall, 70.000 tons of demolition materials were upcycled (concrete, flatglass, aluminimium) for reuse on site after re-manufacturing, 1.646 tons of materials and components (0,6% of total weight) were reclaimed to be reused on site and on other sites; only 710 tons have been evacuated (Figure 4).

The towers' refunctionalization and adapatation project was, then, structured according to the principles of modularity and Design for Deconstruction, to maximise materials and components' future recovery.

4.2 Taitsugar Circular Village (Taiwan)

In the Shalun Smart Green Energy Science City in Taiwan, one of the first 'circular villages' in the world has been realised, the TaiSugar Circular Village (Bio-architecture Formosana, 2021), consisting of three housing blocks and a courtyard with shared spaces, aquaponic cultivation, phyto-purification, and solar energy production by BIPV (Building Integrated Photovoltaic) (Figure 5). The good practice is listed in the Circular Taiwan Network database.

The buildings were designed with a life-cycle and circular approach, relying on a modular and prefabricated system for both the load-bearing structure and the façade construction, using a mixed system of steel and wood (Cross Laminated Timber panels) to make assembly and disassembly more efficient. Insulating blocks made of recycled LED glass were used for the façades and interior partitions respectively.

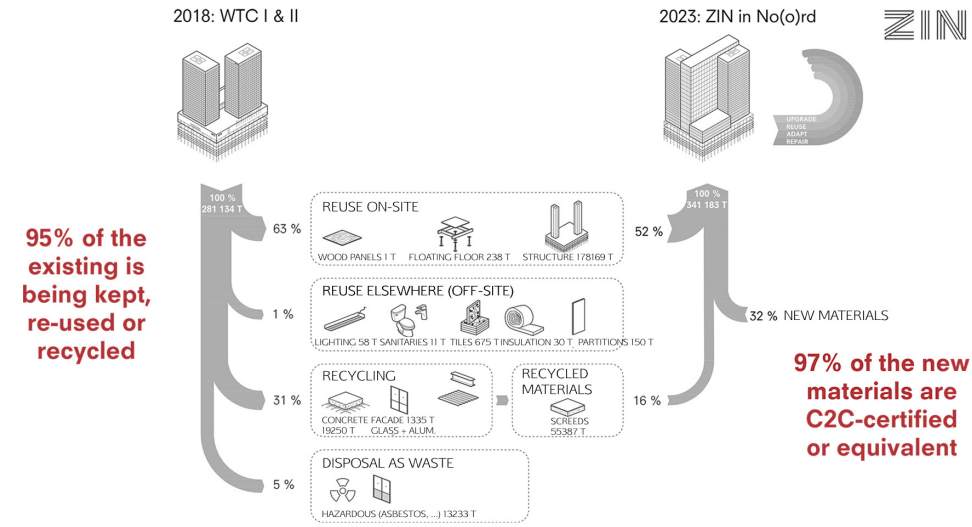

FIGURE 2: Building as Material Bank concept as implemented in the deep renovation of two of the four towers of the World Trade Centre in Brussels, within the ZIN Project (Source: M. De Moradiellos, Drees and Sommer, ECESP Circular Talk 2021).

FIGURE 3: Local closed-loop recycling of concrete in the ZIN Project in Brussels, BE (Source: M. De Moradiellos, Drees and Sommer, ECESP Circular Talk 2021).

FIGURE 4: Overview of the stocks of reclaimed building components disassembled from the World Trace Centre towers and destined to onsite/offsite reuse.

The BIM technology was also applied to integrate material and structure information to facilitate assembly and disassembly. The digital twin of the buildings will serve as a material database for future replacement or reuse, through the use of Material Passports integrated in the BIM models (Figure 6). With a view to the building as a 'bank' of construction materials, thanks to reversible connection systems and the modularity of the components, the reclaimed materials used include wooden components obtained from the dismantling of dilapidated buildings, re-

FIGURE 5: Overall view of the Taitsugar Circular Village in Taiwan (Source: Bio-architecture Formosana).

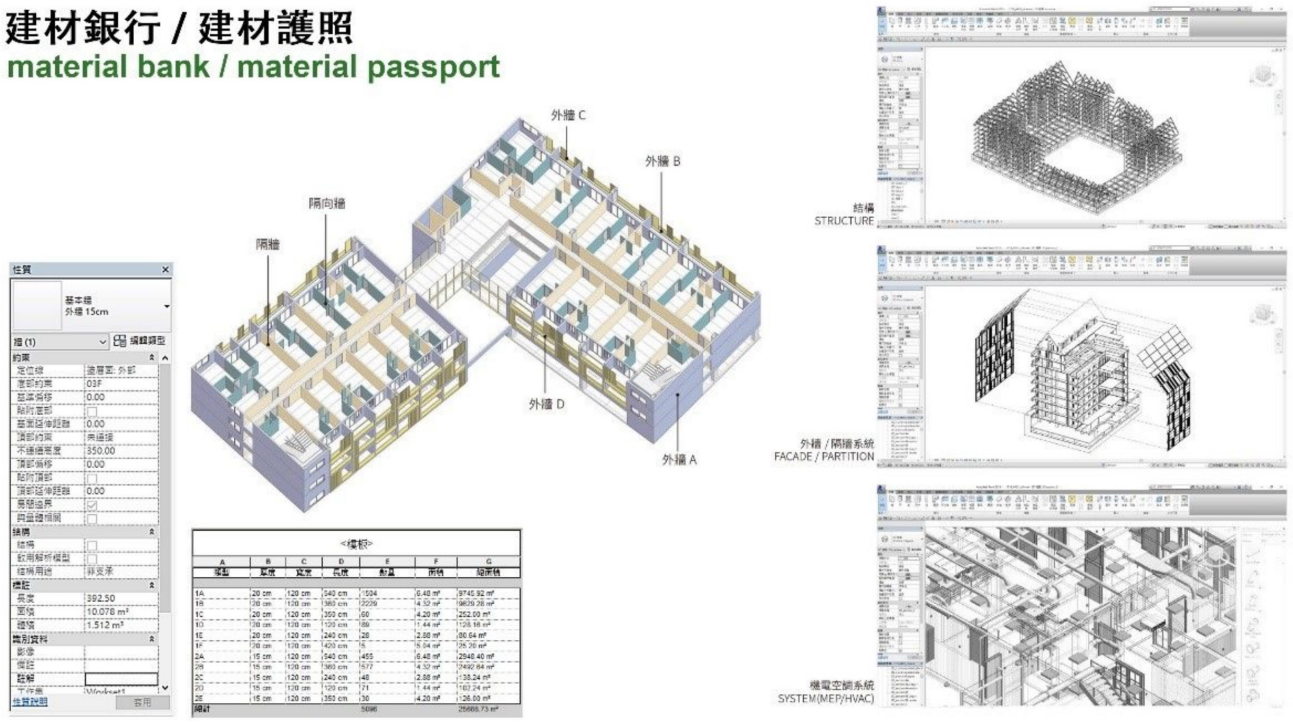

FIGURE 6: Material passports collected in the BIM models of the Taitsugar Village's buildings (Source: Bio-architecture Formosana).

used as structural components for one of the pavilions and railway tracks reused as fencing.

Moreover, a key aspect of this good practice is the servitisation of different elements and installations of the buildings. Lift blocks, lighting fixtures, furniture and sanitary components have been 'rented' rather than purchased (product as service) (Figure 7). The servitisation approach, already tried out in some pioneer projects starting with the lighting systems in large facilities such airports, is thus extended to various technical elements of the building, which can be better maintained. The flats are rented out to residents to whom the manager will provide all the necessary maintenance, from the building to furniture and appliances. In this way, the user will pay to use and not to own. In addition, the rental of cars, scooters and electric bicycles for residents has been introduced.

Overall, Taitsugar Village is a concrete example of a fully circular settlement, where the flows of building materials, energy, water and food are all managed in an efficient, closed-loop and local way.

4.3 Ricehouse: building materials made from rice husk and straw

The Italian Benefit company Ricehouse (listed in the ICESP and ECESP good practices' databases) has developed a product innovation based on the valorisation of production waste from the rice value chain. Most of the secondary materials generated by primary agricultural production are treated as waste, nothwithstanding their intrinsic market value, potentially exceeding the disposal costs. For each hectar of soil dedicated to rice production, 7 tons of rice is produced, while residues are on average 10 tons. The good practice regards the development of innovative construction products valorizing the by-products of rice cultivation, such as husk and straw. For example, Ricehouse has industrialised the production process of pre-stressed wood and rice straw frames, to build prefabricated passive houses. In such constructive system, rice straw insulation offers a balanced thermal comfort and requires minimum energy consumption for heating the building, which can be provided by renewable sources.

Other very innovative products are made from rice husks and lime: natural mortars are made by mixing air lime and rice husks. The most interesting ones can be used as plasters (Figure 8) and aesthetically enhance the presence of waste fibres in the mix. One of the company's most innovative clay-based mixes also guarantees the possibility of 3D printing large-scale constructions (Figure 9).

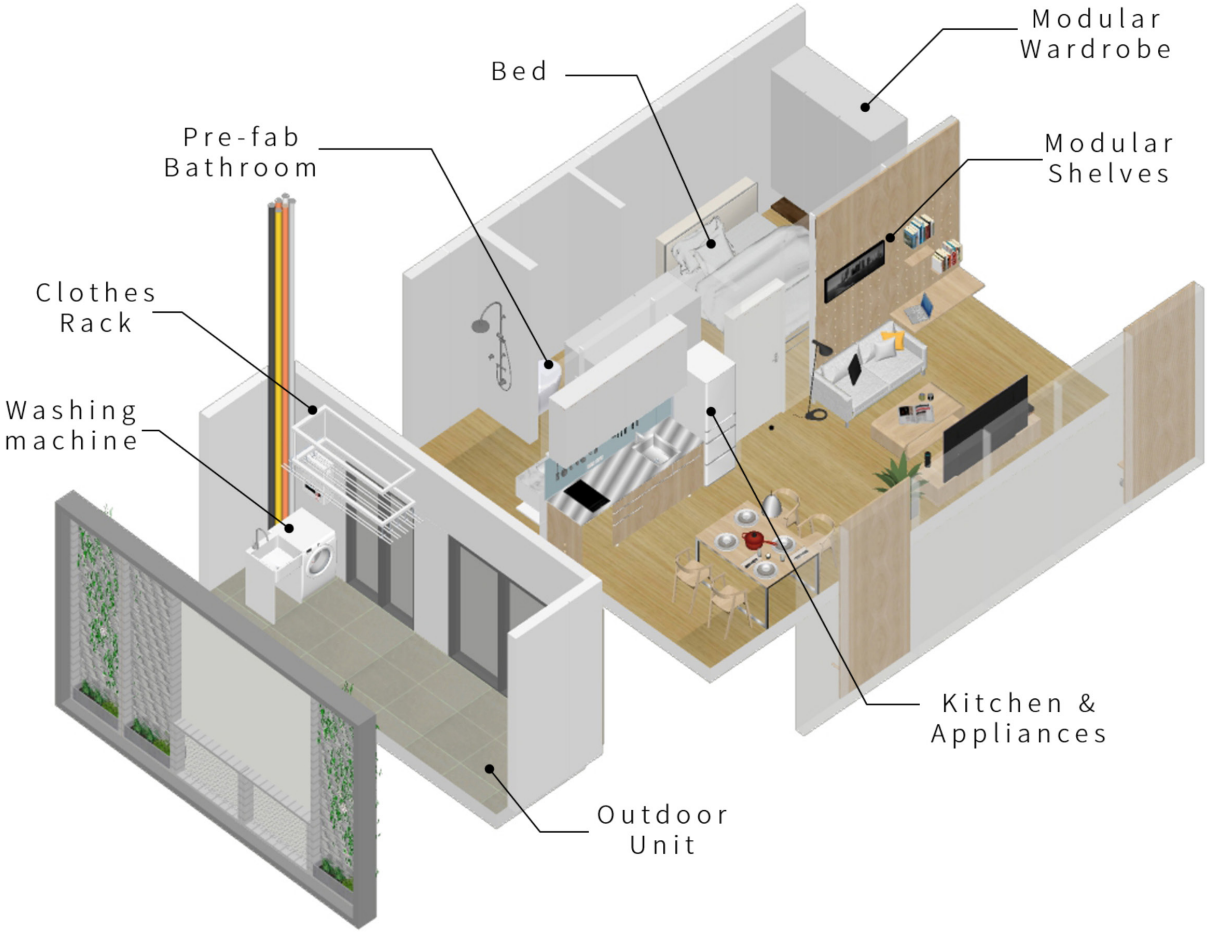

FIGURE 7: Prefabricated installations blocks rented through a servitisation procurement model, within the modular housing units (Source: Bio-architecture Formosana).

FIGURE 8: Examples of Ricehouse lime and rice husk plasters (Source: https://www.ricehouse.it/prodotti/finiture/).

FIGURE 9: Gaia Project by Ricehouse, 3D printed house with biomass insulation built with a 3D Crane WASP printer and natural materials from the landscape nearby, in a blend of natural materials including clay, ground sand, rice straw and rice husk (Source: https://www.ricehouse.it/storie/gaia/).

4.4 Production of concrete with a certified content of recycled aggregates compliant to the Italian Green Public Procurement Minimum Environmental Criteria

The good practice, coming from the ICESP database, refers to the Italian company Italcementi, among the first large national companies to have activated concrete production lines for construction, and not for infrastructures as usual, with mixes that incorporate recycled aggregates from the recovery of inert demolition waste. The circular economy practice implemented by the company consists in the production of pre-packaged concrete and filling mixes with partial replacement of natural aggregates, which represent one of the main constituents of concrete, with

aggregates recycled from demolition concrete or secondary raw materials from industrial origin (industrial aggregates) such as, for example, steel mill slag. The concretes produced reach a total content of recycled material varying between 8 and 15%. The filling mixes have a total content of recycled material larger than 70%. These average recycled contents are compliant to to the Italian Green Public Procurement Minimum Environmental Criteria for buildings (in force since 2016), which require concretes with at least 5% recycled content.

In the period 2014-2019 the company used approximately 64,400 tons of aggregate recycled from C&D waste and approximately 42,450 tons of industrial aggregates. Evaluation and certification of environmental impacts and recycled percentages through LCA studies and EPD declarations (Type III Environmental Product Declarations) made it possible to use such products in works subject to Green Public Procurement.

4.5 Madaster platform aimed at sharing information about building materials

Madaster, the 'Materials Cadastre' (Figure 10), is a good practice from the ECESP database. It is the first platform that facilitates the centralized and standardized web-based generation and registration of materials passports in the construction and infrastructure sector. It is operational in 5 European countries, with projects registered all over the world.

The platform generates and records passports of materials, products, buildings and areas, providing a detailed inventory with information on quantity, quality, size and location of all materials, components and products used in a specific construction intervention (Figure 11). Furthermore, the platform calculates a financial evaluation (current and expected future residual value of the materials) and provides an overview of the environmental impact (Circularity Index, embodied carbon). The passport can be adapted and enriched over time, providing a dynamic repository of data, which can also be archived at a specific moment. The platform is interoperable with BIM models.

4.6 Concular platform for the exchange and assessment of reclaimed building components

Concular, a good practice from the ECESP database, is a digital platform (Figure 12) that allows the recirculation of building materials. The platform targets professionals in the construction industry, such as portfolio holders, project developers, building owners, manufacturers and architectural firms.

The software allows new and existing building materials to be digitized using AI technology. It also measures embodied carbon emissions and quantifies how these can be reduced by recirculating a building's materials. Architectural firms can also source low-carbon reclaimed materials and low-carbon recycled materials using the platform. The platform therefore supports the collaboration between the construction value chain's actors.

Connected to Concular is the Restado.de marketplace that brings building materials from demolition or oversupply in contact with the demand coming from new construction projects. Restado's mission is to extend the life cycle of building materials, which are reused many times. Restado's target group consists mainly of craftsmen, small construction companies and private owners.

5. CONCLUSIONS

This paper demonstrates the role of collaborative platforms in scaling up effective circular practices for

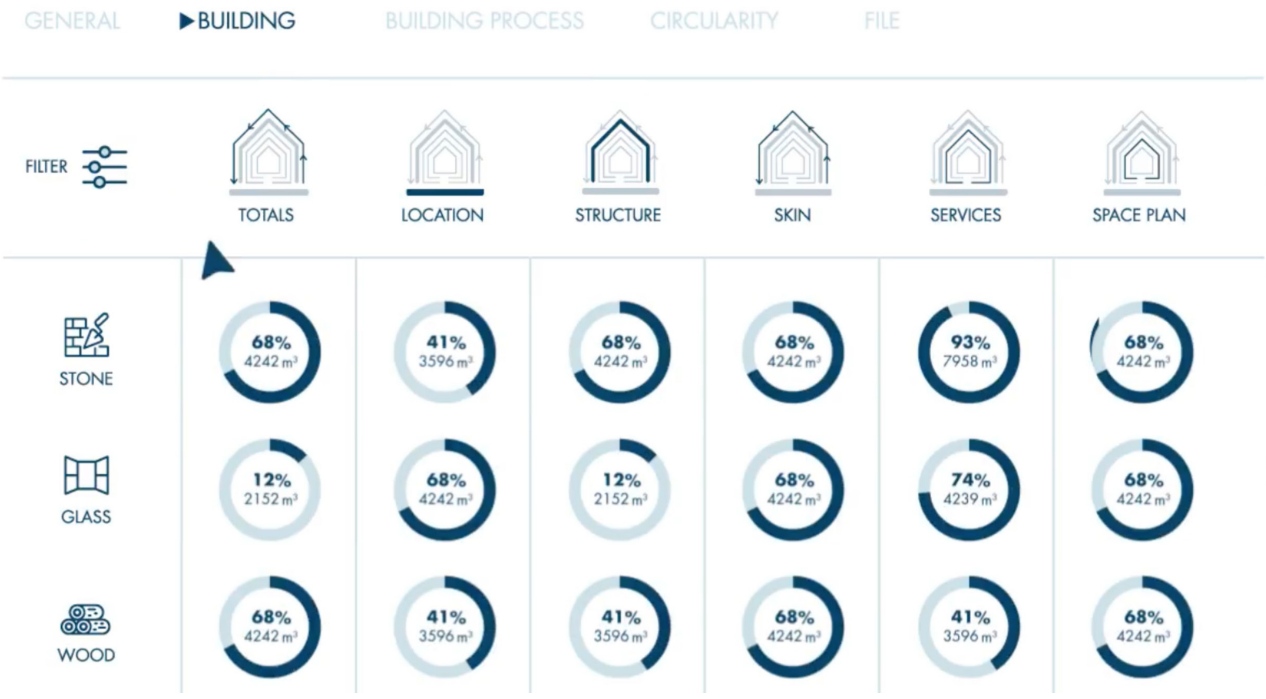

FIGURE 10: Madaster platform's interface for building materials' mapping and registering (Source: https://madaster.com/).

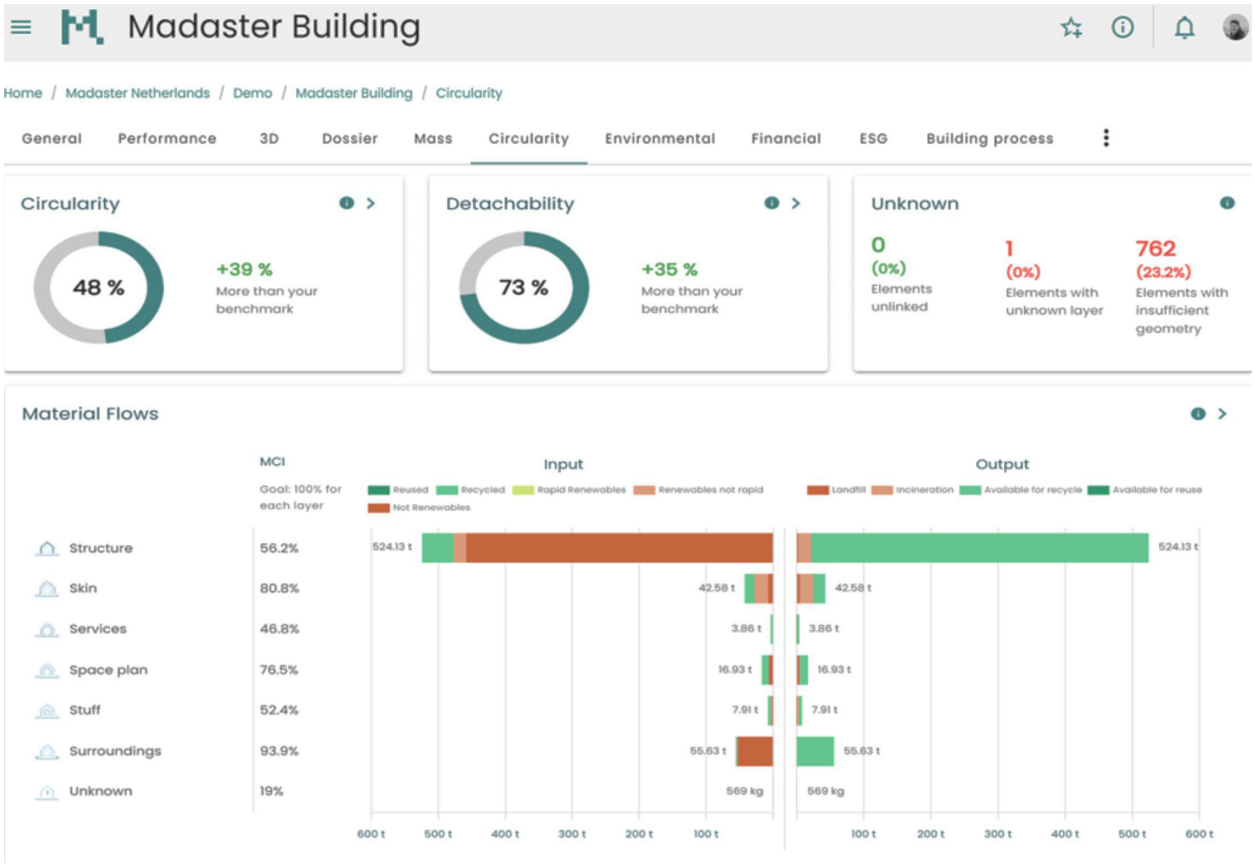

FIGURE 11: Materials mass balance and embodied carbon estimation in the Madaster platform. (Source: https://madaster.com/).

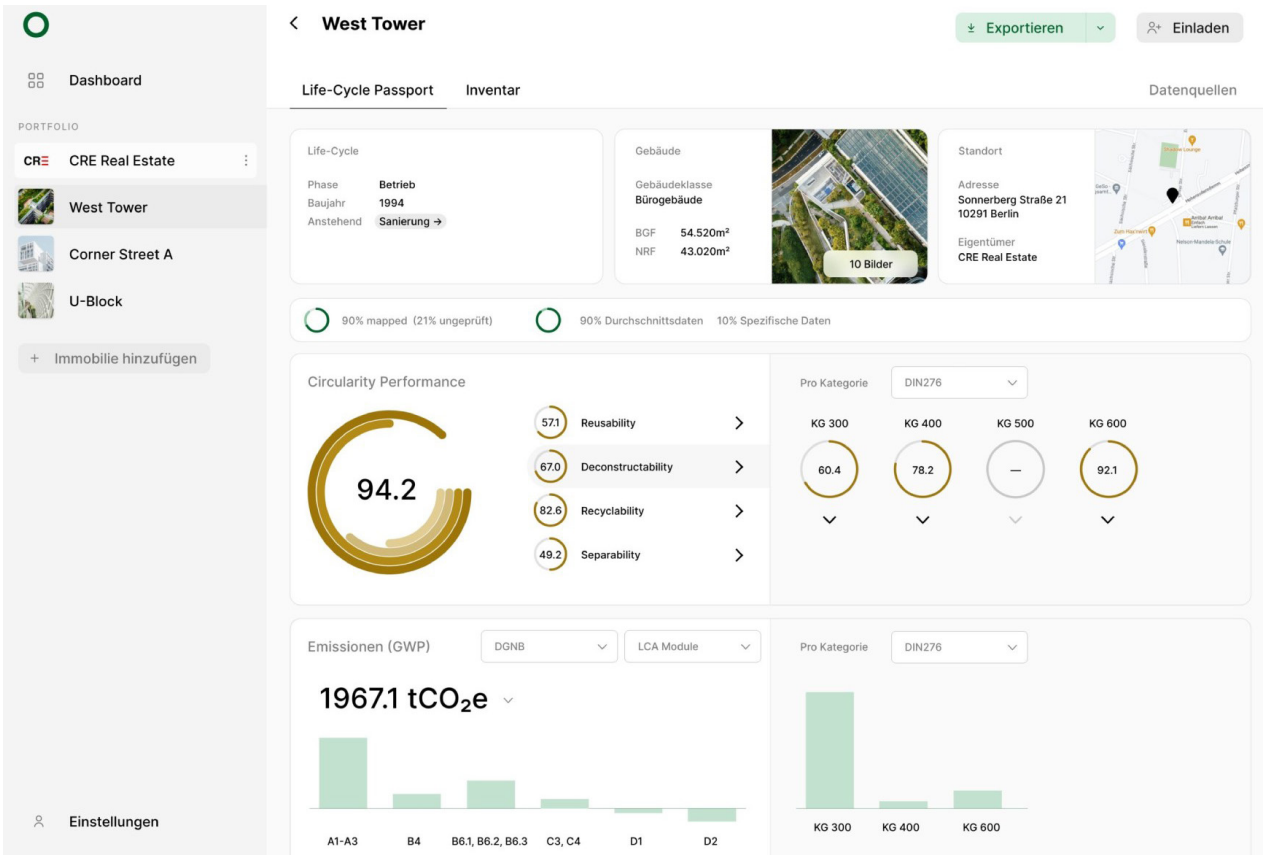

FIGURE 12: Concular platform interface (Source: https://concular.de/).

the built environment, serving as tools for implementing the quintuple helix model. The results reveal how national-level stakeholder discussions and exchanges have led to the identification of nine strategic actions encompassing various forms of innovation. These actions span from product and process innovations to more intricate forms related to consumption and organizational models, including supply chains. For each of these actions, we presented some exemplary practices selected from those identified in the collaborative platforms under review (ICESP, ECESP, Holland Circular Hotspot, Circular Taiwan Network). These cases showcase product, process, and organizational innovations, illustrating how circular economy principles can be applied to the built environment. The benefits include enhanced resource efficiency, reduced waste, improved environmental quality, and increased sector competitiveness. These showcased examples exemplify the identified strategic actions and underscore how collaborative platforms serve as reservoirs of innovation and knowledge for transitioning to circular construction.

The aforementioned good practices serve as examples of the strategic actions identified through stakeholder engagement activities within ICESP. Among these, the most recurring actions in the selected cases include: "Creation of a collaborative platform", "Improved material traceability and transparency of information to extend the life cycle and raise the quality of construction products", and "Development of innovative products with recycled content, certified for the public and private markets, particularly from C&D waste". These three strategies are evidently interconnected, notably demonstrated in the advanced good practice of the ZIN Project. These good practices underscore how collaborative platforms act as reservoirs of innovation and knowledge for transitioning to circular constructions and facilitating their scale-up. Moreover, the work emphasizes how the quintuple helix approach, based on cooperation between institutions, universities, industries, civil society, and the natural environment, fosters the creation, production, application, dissemination, and continuous use of knowledge and innovation, promoting eco-innovation and eco-entrepreneurship in the construction sector.

However, some limitations are present in this contribution. It is based on an exploratory qualitative methodology utilizing multiple case studies and participatory action research, which does not allow for statistical generalization of results or systematic comparison of different experiences. Furthermore, the analysis focuses only on a few selected good practices from the surveyed collaborative platforms, which are not exhaustive of all possible circularity solutions applicable to the construction sector. Nevertheless, ongoing research activities aim to expand the mapping of good practices traceable to the strategic actions identified in the stakeholder consultation ran in ICESP. This will be accomplished through a more structured census focused on specific types of good practices, particularly digital platforms enabling collaboration between different actors, traceability of components, promotion of reuse and recycling, valorization, and facilitation of meeting between demand and supply of recovered materials and components. These platforms are proving to be strategic for the scale-up of circular project good practices.

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