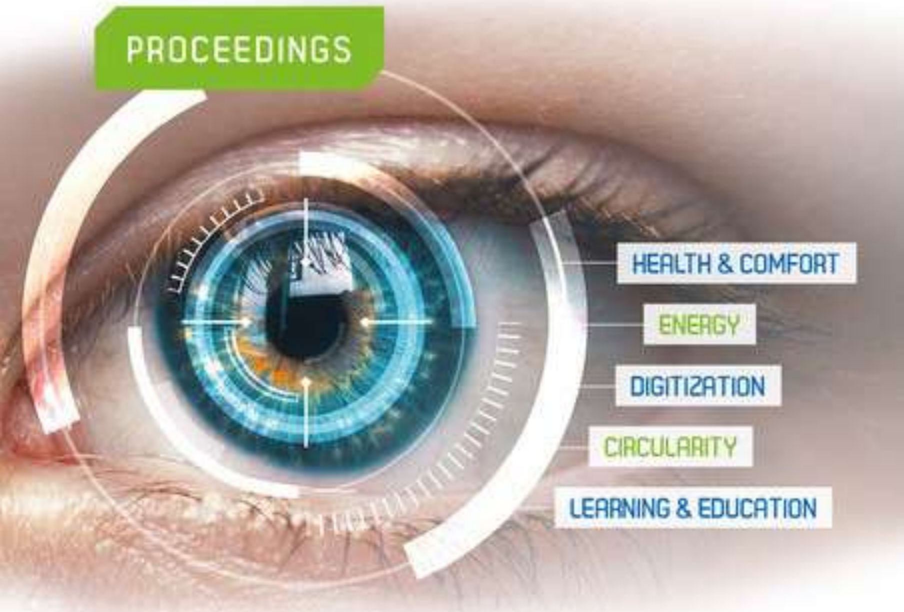
CLIMA 2022

EYE ON 2030 | Towards digitalized, healthy, circular and energy efficient HVAC

REHVA 14th HVAC World Congress

22nd - 25th May, Rotterdam, The Netherlands



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Preface

The 14th REHVA HVAC World Congress CLIMA2022 challenges advances in technologies for smart energy transition, digitization, circularity, health and well-being in buildings. How can we create circular buildings, fully heated, cooled and powered by renewable energy? How can we design human-centered indoor environments while mastering life-cycle costs? How can we also include their integration into infrastructure for energy, health, data and education? The congress is organized around 5 themes.

Theme 1: Health & Comfort

The achievement of health and comfort of people in the built environment, whether at home, at work, at school, or enjoying free time, is a complex subject that involves physics, behaviour, physiology, energy conservation, climate change, architecture, engineering and technology. The way people feel, experience and behave in their environment is related to the quality of their environment, described by the thermal, air, lighting and sound qualities, but also to the ability of the buildings and systems to respond to people's changing needs and preferences and the ability of people to respond to new buildings and systems. As shown by the outbreak of the COVID-19 pandemic, building systems have to provide a resilient environment not only on the long term (as climate change is evolving) but also in the short term (for example during a pandemic). CLIMA2022 challenges advances in intelligent interfaces and interaction between building, indoor climate systems and humans and seeks for new approaches to health & comfort in relation to low-energy buildings, energy-efficient retrofit and pandemics.

Theme 2: Energy

CLIMA2022 considers fossil-free energy use in the built environment of vital importance. Development of building services systems using heat, cold and electricity from renewable resources is accelerating, creating a need for flexibility and therefore for energy storage and inter-building energy exchanges. Following this there is also a need for innovative HVAC products and for performance optimization via improved design, operation and maintenance of the various integrated mechanical and electrical sub-systems. This typically includes reduction and balancing of the energy demands for heating, cooling and ventilation. While this is not exactly trivial in new buildings, it poses huge technical, social, economic and political challenges for existing buildings. Obviously the solutions will vary across countries. Exchanging experiences and learning from each other are the main objectives of CLIMA2022. When homes become small energy plants, or when large building complexes start to exchange energy, or when smart data companies control energy consumption, then the government, grid operators, energy companies, financial institutions and our sector need to respond.

Theme3: Digitization

CLIMA2022 considers digital solutions that encourage the energy transition in the built environment. Solutions are expected in the areas of (predictive) digital twinning, data-driven smart buildings, data management, and continuous commissioning. Nowadays digital solutions must be capable of handling a wide variety of HVAC systems and even be self-learning in detecting trends and process anomalies. Stand-alone (add-on) or embedded solutions are possible, but system architectures must include large scale deployment. Monitoring strategies are needed that also bridge the gap between Building Automation and Control Systems (BACS) and Building Information Modeling (BIM), and enable lifetime-cost control using system and building-contextual data. Large-scale monitoring of energy, comfort and life-cycle cost performances at an affordable cost level are needed in support of business cases and policies. Finally, the recent COVID-19 pandemic has triggered research on digital-focused design, monitoring and control of ventilation systems, in relation to overall comfort and health. This includes AI algorithms for fault detection and diagnosis, pattern recognition and anomaly detection.

Theme 4: Circularity

As a result of a growing population worldwide and the need for comfortable and healthy indoor environments, a massive building challenge lies ahead with the development of new building projects as well as the need to upgrade the existing building stock. To ensure a future-proof, sustainable economy for future generations, the reduction of the use of primary resources is essential. Circularity aims at closing and connecting material, water and energy flows while eliminating waste and reducing the demand for primary resources. The HVAC sector has a particularly high potential to contribute to circularity. Cycling energy, air and water flows is its core business. Components are frequently subject to upgrades and change. The retention and reuse of valuable materials and components offer business opportunities. However, the associated benefits have not yet translated into a large-scale market breakthrough. The sector needs a clear vision on how to achieve circularity goals, based on innovative strategies and an integrated approach with regard to circular design, product technology, business models, and management.

Theme 5. Learning & Education

The European targets around the energy transition in the built environment are huge. To realize the transition towards an energy-efficient, circular, digitized and healthy built environment, an upscaling of solutions is urgently needed. Dissemination of technical innovations and proven knowledge and approaches is needed. The building services sector is essential for realizing this transition: next to delivering the workforce for designing, placing and maintaining all energy and indoor climate equipment in buildings and neighborhoods, the sector also acts as innovator and is the axis between the construction, energy, IT and health sectors, integrating knowledge from these fields. Rapid changes in energy and HVAC engineering techniques and systems and in contracts and processes make it necessary to accelerate the uptake of knowledge in these areas. This means that continuous professional development of the current workforce and the education of new employees is necessary. There is a growing need for in-company, sectoral and cross-sectoral learning communities.

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The Editors

CIRCULARITY

The circularity of renovation solutions for residential buildings

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Abstract. Construction and demolition waste accounts for approximately a third of all waste generated in the EU. Adopting circularity principles to the construction processes aims to reduce waste generation. The focus of the study was on circular renovation solutions as renovation is becoming increasingly important. The renovation wave for Europe sets a target to double annual energy renovation rates in the next ten years. This study analyses circularity of the renovation concepts for the pilot renovation cases in seven countries in different climate zones in Europe. Analyses were carried out within the DRIVE 0 project funded by the European Union's Horizon 2020 research and innovation program. Pilot buildings are detached houses and apartment buildings with different renovation interventions. Design for Disassembly criteria and embodied energy and embodied CO_2 analyses combine design and material use aspects. Results show that in terms of design for disassembly indicators, prefabricated modular solutions have much higher circularity potential than the traditional wall insulation systems due to the low disassembly and reusability potential of external thermal insulation composite systems (ETICS. The environmental impact of the prefabricated insulation solutions is lower than and ETICS solutions. Although the difference between prefabricated and ETICS solutions in terms of environmental impact is smaller than in terms of disassembly and recovery options.

Keywords. Circular renovation, design for disassembly, embodied energy, embodied carbon.
DOI: https://doi.org/10.34641/clima.2022.333

1. Introduction

Adopting circularity principles to the renovation processes helps reduce waste generation in the construction industry. Construction waste generated during renovation works is an important issue because the renovation wave for Europe sets a target to double annual renovation rates in the next ten years.

Previous research has shown that the construction sector is resistant to circularity and the need to develop disassemblable building products is necessary (1). The sustainability of deep renovation solutions is often not assessed during the design phase. Current deep renovation solutions are mainly based on operational energy use and do not consider the carbon footprint aspects.

Practices for circularity in the construction industry aim at reducing the amount of waste generated at the end of the life cycle of a building (2). An essential aspect of increasing the reuse possibilities of building materials and products is modularity. Previous research and development projects have demonstrated prefabricated modules for building renovation (3). The next step would be to link prefabrication and modularity with circularity.

This study analyses circularity of the modular and non-modular external wall insulation solutions for pilot renovation cases in Europe. The pilot renovation cases were selected as part of an EU-funded project DRIVE 0 (4), developing circular deep renovation solutions. The goal for DRIVE 0 is to provide solutions to speed up the deep and circular renovation process.

2. Methods

There is currently no single methodology for circularity assessment and many different indicators exist for evaluating the circularity of construction products and buildings. Some indicators are based on one characteristic (durability, the recycled share of materials, etc), and some indicators include wider impacts (economic, environmental, etc). In the current study, circularity assessment includes design for disassembly criteria and environmental impact. The purpose of the method selection was to have an approach with few input data which would be useful also for practitioners.

2.1 Circularity assessment

Methodology for circularity assessment is based on the design for material recovery principles (5). The indicator used to assess the degree of circularity of the renovation solutions is the simplified version of the DfD criteria proposed by AlbaConcept (6). Circularity is assessed based on four variables with relative weights depending on specific components and joint features.

Circularity assessment criteria:
1. type of connections,
2. accessibility of connections,
3. crossings,
4. form containment.

Tab. 1 - Type of connection.

Dry connection	Dry connection	1.0
	Click connection	
	Velcro connection	
	Magnetic connection	
Connection with added elements	Ferry connection	0.8
	Corner connections	
	Screw connection	
	Bolt and nut connection	
Direct integral connection	Pin connections	0.6
	Nail connection	
Soft chemical compound	Kit connection	0.2
	Foam connection	
Hard chemical connection	Glue connection	0.1
	Pitch connection	
	Weld connection	
	Cement bond	
	Chemical anchors	
	Hard chemical connection	

Tab. 2 - Accessibility of connection.

Freely accessible	1.0
Accessibility with additional actions that do not cause damage	0.8
Accessibility with additional actions with reparable damage	0.4
Not accessible - irreparable damage to objects	0.1

Tab. 3 - Crossings.

Modular zoning of objects	1.0
Crossings between one or more objects	0.4
Full integration of objects	0.1

Tab. 4 - Form containment.

Open, no inclusion	1.0
Overlaps on one side	0.8
Closed on one side	0.2
Closed on several sides	0.1

On a product level, material selection is also added as a criterion to assess the circularity of materials used for renovation:
1. Repaired: restoring to good working order, fix, or improving the damaged condition.
2. Reused: using an item for its original purpose or to fulfill a different function.
3. Recycled: converting waste material into reusable material by breaking down items to make new materials.
4. Refurbished: restore to original order & appearance with new materials.
5. Remanufactured: using a combination of reused, repaired, and new parts.

Tab. 5 - Materials and products.

Locally repaired, reused building components and materials	1.0
Biobased materials	0.8
Recycled and upcycled building components and materials	0.6
Refurbished, remanufactured materials	0.4
Non-biobased virgin materials or products made from non-biobased pure materials	0.1

The circularity index is calculated based on the average of the five subcategories. To achieve a high degree of circularity, the average index of the subcategories must be above 0.80.

Assessing degree of circularity:
1. index < 0.60 Low degree
2. index ≥ 0.60 Medium degree
3. index ≥ 0.80 High degree

2.2 Environmental impact assessment

Methodology for environmental evaluations is based on embodied energy and embodied carbon of the buildings (7).

Embodied energy and CO_2 for each component are assessed by filling the material spreadsheet. For each material, the quantity and the total amount are specified. The existing building envelope is excluded from the analysis, as existing constructions are often not changed during the renovation.

Tab. 6 – A material spreadsheet.

Mass of materials	kg; kg/m^2
Embodied Energy of materials	MJ; MJ/m^2
Embodied CO_2 of materials	kg; kg/m^2

The data results in an overview of material mass, embodied energy, and embodied CO_2. The ICE (8) database for the built environment was used for the materials embodied energy and embodied CO_2.

Tab. 7 – Embodied energy and CO_2 of materials.

Material	Embodied energy, MJ/kg	Embodied CO_2, kgCO_2/kg
Sawn timber	7,4	0,2
Stone wool	16,8	1,12
Glass wool	28	1,35
Cellulose wool	2,12	0
Fibre cement panels	15,3	1,28
Expanded Polystyrene	88,6	3,29
General plaster	1,8	0,13

2.3 Case studies

Seven demonstrators were selected to analyze different residential buildings in different climate zones in Europe. All buildings are residential buildings but have different functionalities: detached houses, semi-detached house, terraced house, and apartment buildings.

Table 8 shows the brief description for each case study building, and Figures 1-7 shows a photo of the building.

Tab. 8 - Case studies description.

Country	Floor area, m^2	Type
Netherlands	144	terraced house
Estonia	2415	apartment building
Greece	109	detached house
Ireland	80	semi-detached house
Italy	470	rural manor villa
Slovenia	232	detached house
Spain		apartment building

Fig. 1 - Dutch pilot.

Fig. 2 - Estonian pilot.

Fig. 3 - Greek pilot.

Fig. 4 - Irish pilot.

Fig. 5 - Italian pilot.

Fig. 6 - Slovenian pilot.

Fig. 7 - Spanish pilot.

2.4 Description of the renovation solutions

Dutch pilot: The assessment of circularity on the product level consist of wooden prefabricated elements of WEBO, indicated in Figure 8.

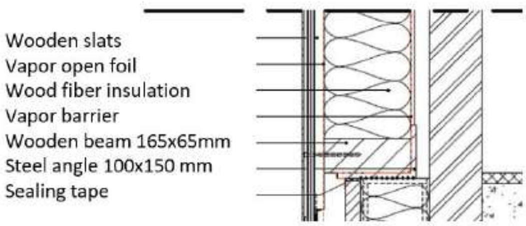

Fig. 8 – Cross-section of façade insulation element.

Estonian pilot: The circularity assessment on product level has been done for the prefabricated façade insulation element. The cross-section of the façade element is shown in Figure 9.

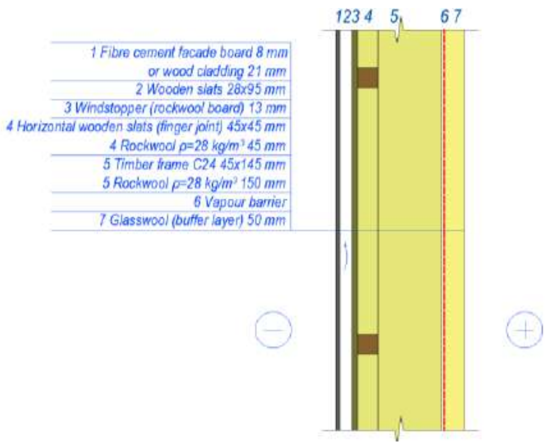

Fig. 9 – Cross-section of façade insulation element.

Greek pilot: The circularity assessment on product level has been done for external thermal insulation composite system (ETICS) based external wall insulation solution.

Irish pilot: The product-level circularity assessment has been done for the prefabricated 2D façade insulation element. The cross-section of the façade element is shown in Figure 10.

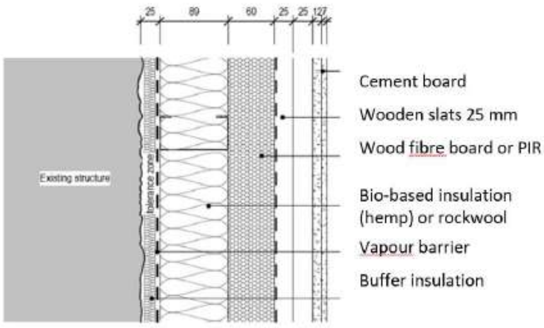

Fig. 10 – Cross-section of façade insulation element – Design Proposal (Coady Architects).

Italian pilot: The assessment of circularity on product level has been done both for the 2D plug&play prefab panels, composed of two layers of high and low-density rock wool (to be applied to the North and West oriented façades), and for the traditional ETICS system in rock wool (to be used to the South and East oriented façades). The final solution that will be implemented may differ from the one presented in the paper, depending on the company's technical requirements during the construction. The cross-section of the façade element is shown in Figure 11.

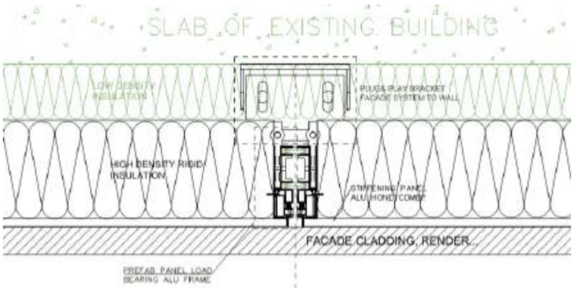

Fig. 11 – Cross-section of façade insulation element – Design Proposal (ALIVA).

Slovenian pilot: The circularity assessment on product level has been done for external thermal insulation composite system (ETICS) based external wall insulation solution.

Spanish pilot: The product-level circularity assessment has been done for the prefabricated green wall façade elements with building-integrated PV panels. The cross-section of the façade element is shown in Figure 12.

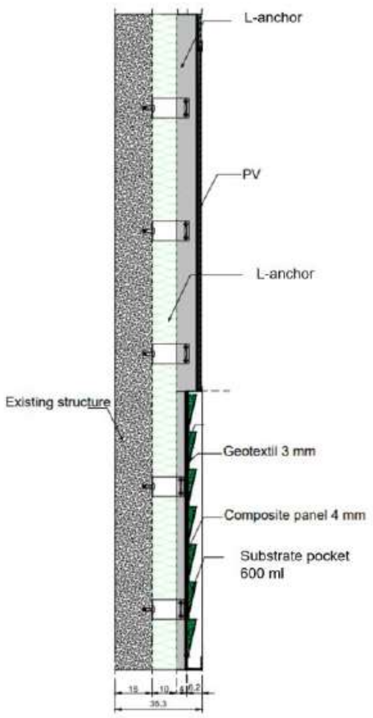

Fig. 12 – Cross-section of façade elements – Design Proposal (Pich Aguilera Arquitectos S.L.).

3. Results and discussion

3.1 Circularity

An example of the Design for Disassembly calculation for Estonian pilot renovation is shown in Table 9. On a product level, a medium degree of circularity has been achieved. Type and accessibility of connections, crossings, and form containment showed a high degree of circularity (>0.8) and material use showed a low degree of circularity (<0.6).

The structure of the insulation element is a timber frame made from finger-jointed structural timber. The circularity of the timber frame is high as timber is biobased material and the use of finger joints reduces production waste. Frame connections are made with screws which allow relatively easy disassembly. Insulation, wind barrier, and façade cladding materials are not biobased or reused. Façade insulation element with cellulose insulation would achieve a higher score but cellulose insulation cannot be used because of fire safety regulations. Estonian pilot building is a TP1 class building that requires at least fire resistance class A2 for insulation material. Cellulose wool has fire resistance class B1.

Results of the Design for Disassembly calculations for all pilot cases are summarized in Table 10. Category averages for external wall insulation solutions are shown for the type of connections, accessibility of connections, crossings, form containment, and materials. Calculations were performed for all layers, and averages of the whole prefabricated insulation elements are presented.

Prefabricated modular solutions have higher circularity potential than the traditional wall insulation systems system due to the low demountability and reusability potential of ETICS.

Although it may be debated whether the circularity benefits of biobased materials are adequately weighted as the material indicators are only 1/5th of the score, and the circularity assessment is mainly based on DfD, bio-based materials show better material circularity potential.

The indicators are also not weighed or proportioned with the material amount (volume or mass), and small elements (vapour barrier) can have a disproportional impact on the results.

Tab. 9 – Circularity of renovation solutions.

	Element	Type of Connection		Accessibility of connection		Crossings		Form containment		Materials	
1	Connection to existing wall	Corner and screw	0.8	No damage	0.8	Modular zoning	1.0	Overlaps on one side	0.8	-	
2	Buffer insulation (glass wool)	Screw and line	0.8	No damage	0.8	Modular zoning	1.0	Open, no inclusions	1.0	Recycled material	0.6
3	Timber framing	Screw	0.8	No damage	0.8	Modular zoning	1.0	Open, no inclusions	1.0	Biobased material	0.8
4	Insulation (stone wool)	Dry	1.0	No damage	0.8	Modular zoning	1.0	Open, no inclusions	1.0	Mainly virgin material	0.1
5	Wind barrier (stone wool)	Screw	0.8	No damage	0.8	Modular zoning	1.0	Open, no inclusions	1.0	Mainly virgin material	0.1
6	Wooden lath	Screw	0.8	No damage	0.8			Open, no inclusions	1.0	Biobased material	0.8
7	Facade cladding (fibre cement)	Screw and seal	0.8	Freely accessible	1.0	Modular zoning	1.0	Open, no inclusions	1.0	Mainly virgin material	0.1
Category average			**0.83**		**0.83**		**1.0**		**0.83**		**0.42**
Circularity indicator		**0.78**				**Medium degree of circularity**					

Tab. 10 – Circularity of renovation solutions.

	Type of Connection	Accessibility of connection	Crossings	Form containment	Materials	Circularity index	Degree of circularity
Dutch (2D prefab)	0.68	0.87	0.83			0.80	high
Estonian (2D prefab)	0.83	0.83	1.00	0.83	0.42	0.78	medium
Greek (ETICS)	0.50	0.10	1.00	0.10	0.10	0.36	low
Irish (2D prefab)	0.84	0.64	1.00	0.83	0.44	0.75	medium
Italian (2D prefab)	0.71	0.88	1.00	0.70	0.54	0.77	medium
Italian (ETICS)	0.27	0.40	0.10	0.10	0.43	0.26	low
Slovenian (ETICS)	0.27	0.40	0.83	0.10	0.10	0.34	low
Spanish (PV facade)	0.82	0.85	1.00	0.82	0.49	0.79	medium

Many building materials would have excellent circularity properties; however, they could not be used for practical reasons. Main obstacles with the use of recycled or biobased materials:

- Absence of necessary certificates (recycled materials)
- Fire safety regulations (a common issue for most of biobased materials)
- Hygrothermal properties (risk for mold growth)
- Higher maintenance need (repainting of the wooden cladding)
- "Factory friendliness" (factories favor rigid wind barrier because of prefabrication effectiveness and to guarantee the angularity of the element)

3.2 Embodied energy and embodied carbon

The Embodied energy and embodied CO_2 calculations are shown in Figures 13 and 14.

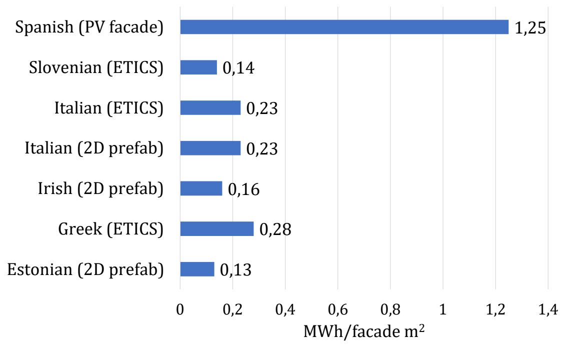

Fig. 13 – Embodied energy of m² of façade area

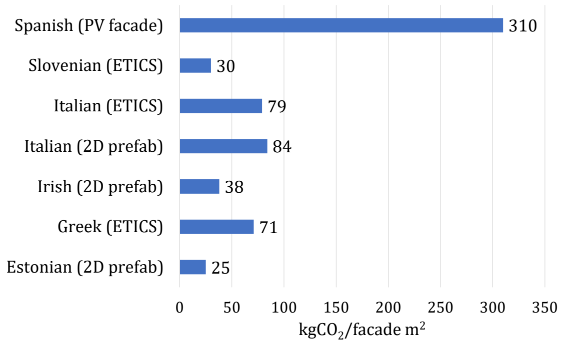

Fig. 14 – Embodied CO_2 of m² of façade area

The high embodied energy and embodied CO_2 content of the Spanish pilot renovation is mainly caused by the steel frames needed to install the PV panels.

Based on embodied energy and embodied CO_2, the environmental impact of the prefabricated insulation solutions and ETICS solutions are in the same range. This is due to differences in the mass of the materials. For example, embodied energy and embodied CO_2 per kg of expanded polystyrene is much higher than materials used in prefabricated solutions but because the expanded polystyrene is light, the embodied energy and embodied CO_2 per square meter of façade can be in the same range as a prefabricated solution with more environmentally friendly materials. Prefabricated insulation panel with timber frame, 200 mm of insulation, and fibre cement board for cladding weigh ~50 kg/m², ETICS solution with expanded polystyrene weighs ~20 kg/m².

4. Conclusions

The research goal was to analyze the circularity of the renovation solutions used for pilot renovations. The indicators used to assess the degree of circularity of the renovation concept are Design for

Disassembly (DfD) criteria and building environmental (with embodied energy and embodied CO_2 as indicators).

The main advantage of modular prefabricated elements is the greater potential for disassembly and reusability. ETICS can only be recycled and cannot be reused without remanufacturing process. Embodied energy and embodied CO_2 of the prefabricated insulation solutions are lower than and ETICS solutions. Prefabricated solutions also allow a wider choice of materials (bio-based insulation materials and cladding) to achieve a low environmental impact. Although the difference between prefabricated and ETICS solutions in terms of environmental impact is smaller than in terms of disassembly and recovery options.

Some building materials have excellent properties in terms of circularity; however, for practical reasons, they could not be used. The main concerns with using recycled or biobased materials were the absence of necessary certificates, fire safety, hygrothermal properties, and higher maintenance need. The final selection of the design solution is a balance between the circular, practical, and financial sides.

Assessment of the circularity of renovation concepts through design aspects (design for disassembly) and material use is a suitable approach. However, the assessment method for design aspects does not consider the proportion of scores relevant to material mass. Materials with low total mass can disproportionately affect the results (for example, air and vapor barrier). At the same time, the additional weighting factor would make the calculation more complex. It's the point of discussion on whether the design for disassembly methodology would benefit from scoring disassembly and material re-use potential based on the mass of the material.

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The datasets generated during and/or analysed during the current study are not available because the project reports containing the analysed data have not been published but the authors will make every reasonable effort to publish them in near future.

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