The tenement's new clothes.

In search for context-feasible and user-adoptable biogenic strategies for Polish inter-war tenement housing revival.

Explore Lab 39 - Research Project

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Abstract

This research explores the potential of bio-based materials and strategies in retrofitting Polish inter-war masonry tenement housing, focusing on circularity while addressing technical requirements, user needs and maintaining historical integrity. Through literature review, market research, cataloguing, and interviews with professionals, the study identifies key challenges in energy efficiency, moisture management, and user satisfaction, proposing bio-based materials such as wood, hemp, flax, wood fibre, straw and many others as effective solutions.

The findings emphasize the importance of navigating technical requirements with user preferences, which include affordability, comfort, and adaptability. By addressing these factors, bio-based solutions offer significant advantages in reducing environmental impact of the refurbishment action while enhancing living conditions. To bridge the gap between innovative practices and real-world application, the study also develops a guidebook and materials catalogue, providing accessible knowledge base about biobased renovation strategies to homeowners, designers, and policymakers.

This work contributes to renewable building practices by demonstrating how bio-based strategies can meet both ecological and practical demands, offering a path toward decarbonizing and futureproofing Poland’s aging housing stock.

Keywords

Bio-Based, Biogenic, Biodegradable, Renewable, Building Materials, Inter-War, Poland, Tenement Housing, Futureproofing, Refurbishment, Guidebook, Catalogue

Introduction

Paradigm in shift.

The global society needs to change drastically to avoid furthering the climatic catastrophe that looms ever stronger over us, and at the same time prepare for incoming effects of our past and current activity. Thus, climate mitigation and adaptation must go together in tandem within architecture and built environment practice. As per the last AR6 IPCC Report, if only CO2 emissions were to be considered, it's estimated that built environment contributes 31% to the whole world emissions, and while this itself is alarming, it is also somewhat optimistic to consider that the AEC sector has great potential to reduce its emissions by a large margin (Fig. 1) [1]. This, however, is progressing too slowly and needs to be accelerated[2]. Given all the knowledge I have so far, doing my best to make it happen is one the only ethical options I can consider in the future as a designer in the built environment.

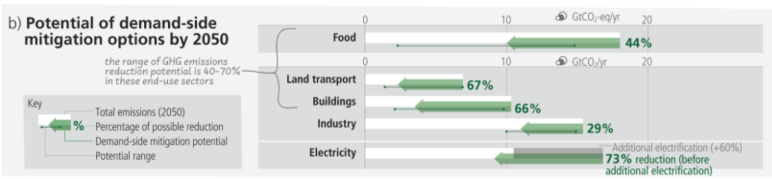

Fig. 1 Potential of demand-side mitigation of GHG emissions for Buildings and other sectors. (IPCC AR6. 2022)

[1] IPCC, "Buildings," *Climate Change 2022 - Mitigation of Climate Change*, 2022, 953–1048, https://doi.org/10.1017/9781009157926.011.

[2] Jennifer Hahn, "Architecture 'Lagging behind Other Sectors' Says IPCC Climate Report Author," April 6, 2022, https://www.dezeen.com/2022/04/06/ipcc-climate-change-mitigation-report/.

While the developing countries will need to find sustainable ways to provide newbuilt housing and healthy environments for their fast-growing populations, the gulf states will use their oil-based riches to invest heavily in carbon sinks or other, hopefully, ethical businesses. The decelerating developed old world, like Europe, according to Indy Johar from Dark Matter Labs, will have to find ways to mostly make use of what is already available. The reuse, refurbishment, retrofitting and in general future proofing is going to be the new normal for architecture practice[3].

Fig. 2 Farmhouse renovation – additional interior insulation using hempcrete. (HempBuild, 2024)

Biobased Future

With most of the growth happening in Asia and Africa. Europe's challenge lies in renovating its ageing building stock, 80% of which is expected to remain standing in 2050. Approximately 35% of EU buildings are at least 50 years old, and 97% fall short of future carbon reduction targets[4]. This

[3] "Lecture: Indy Johar – Designing Our Futures | Live Stream - YouTube," accessed October 20, 2024, https://www.youtube.com/live/knDC8hXDdhE.

[4] World Green Building Council, Ramboll, and C40 Cities, "Bringing Embodied Carbon Upfront" (London, September 2019), www.worldgbc.org/embodied-carbon.

underscores the importance of addressing both new construction and renovation in the pursuit of net-zero emissions.

Embodied carbon, or sometimes referred to as upfront carbon, encompassing emissions from material production to end-of-life, can contribute as much as 50% of a building's total carbon footprint[5]. The situation becomes increasingly significant as buildings become more operationally efficient, highlighting the urgency of minimizing upfront emissions.

To limit global warming to 1.5°C, the building industry must reduce its emissions by 96%[6]. For new housing in Denmark, this translates to a target emission level of 0.4 kg CO2eq/m2/year, assuming a constant construction rate, which is quite conservative. This reduction should ideally be achieved between 2029 and 2036[7]. As Martha Lewis noted during the Obel Award Talk – *"we simply do not have the carbon budget left"* nor confidence any more to build something long lasting hoping it wouldn't be demolished in 20 years, while overlooking obvious low embodied carbon alternatives[8]. So, everything needs to happen with keeping track of the overall carbon balance of all interventions, keeping the embodied energy and pollution as low as possible in the long run, and bearing in mind the exergy and anergy flows to take advantage of them properly[9].

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[5] Lisa Burns et al., "Reducing Embodied Carbon in Cities: Nine Solutions for Greener Buildings and Communities," April 2024.

[6] Reduction Roadmap (2022), "Reduction Roadmap: Preconditions and Methodologies.," 2022, 25.

[7] Reduction Roadmap (2022), 27.

[8] Sam Draper et al., "Embodied Emissions" (Obel Award Talks, July 3, 2023).

[9] David Benjamin, ed., *Embodied Energy and Design : Making Architecture between Metrics and Narratives* (Columbia University

So far, the safest, proven, and most natural solution is to simply build with what is readily and locally available, without much added energy or materials, meaning all biogenic materials like timber, hemp, natural fibres, bamboo, adobe and many others. Those have multiple benefits, among them, for example, carbon sequestration potential[10]. They absorb carbon during their growth, and after harvest, new biomass can be planted in their spot, which can offset emissions from other lifecycle stages. Additionally, such materials can be easily recycled, which is true also for steel or some other carbon intensive materials, but recycling cannot be taken for granted oftentimes. Even better, if recycling is not possible, bio-based materials just biodegrade gracefully. One could go on mentioning other issues that commonly used non-bio-based materials share, like chemical or microplastic pollution etc.

There is additional, less technical and vaguely tangible virtue of bio-based materials, which is ingrained in us over millennia of shaping our built environment with what was available – the natural warmth and pleasant aesthetic familiarity to them. They simply can be digested. Only recently did people started seeing doubt in them while exploring all the new oil-, concrete- or steel- based alternatives.

Thus, delivering on all those qualities, I think, requires considering almost exclusively bio-based low embodied

GSAPP, 2017), https://discovery.upc.edu/iii/encore/record/C__Rb1498725__Sembodied energy__Orightresult__U__X6;jsessionid=E0F52135AB1C74325D4291193110D085?lang=cat.

[10] World Green Building Council, Ramboll, and C40 Cities, "Bringing Embodied Carbon Upfront," 26.

carbon material solutions. That is the first premise of my interest and position as an architect.

Including the User in futureproofing

I also strongly feel a connection with teachings of Giancarlo de Carlo relating to architecture of participation. The *"prospect of taking architecture away from the architects and giving it back to the people who use it"*[11] is one I am very interested in along the author (Fig. 3). I look forward to enabling as much as possible a democratisation of design and its pliability not only in the concept stage but also after completion, allowing a building to mutate and co-evolve with its users as much as it is reasonably possible. Too often it still happens that *"the wishes of future users are either ignored on principle or overthrown by the application of models which suit the interests of the promoters of the visions of the designer"*[12].

There is a considerable body of literature regarding the user adoption and preferences for refurbishment interventions, especially in western European[13] and Mediterranean contexts[14]. "Beyond the Current" is one example of a long running research project regarding futureproofing of the

[11] Giancarlo De Carlo, "An Architecture of Participation," *Perspecta* 17 (1980): 77, http://www.nomads.usp.br/virus/virus18/?sec=4&item=3&lang=en.

[12] De Carlo, 78.

[13] Roberta Cucca and Michael Friesenecker, "Potential and Limitations of Innovative Housing Solutions in Planning for Degrowth: The Case of Vienna," *Local Environment* 27, no. 4 (2021): 502–16, https://doi.org/10.1080/13549839.2021.1872513.

[14] Lise Desvallées, "Low-Carbon Retrofits in Social Housing: Energy Efficiency, Multidimensional Energy Poverty, and Domestic Comfort Strategies in Southern Europe," *Energy Research and Social Science* 85 (March 1, 2022), https://doi.org/10.1016/j.erss.2021.102413.

Dutch inter- and post-war walk-in residential housing, thoroughly seeing into residents' comfort and aesthetic preferences on a large sample size[15]. Such research endeavours, however, to be done properly and yield meaningful contribution to knowledge, are not feasible within the timeframe given for graduation research. Thus, my research is going to be reduced in scope. There is, nonetheless, a need for such research done in the Polish context and I hope someone will begin the work soon. There are already publications in the Polish context that pertain to refurbishment of housing and public use buildings[16], however, they serve as general guidebooks in the building and economical context, not necessarily in architectural or aesthetic one[17]. They provide knowledge about the current market standards, which are by no means biobased, and yet, those do not consider sufficiently proven user adoption rate or their preferences.

[15] "Beyond the Current," accessed October 16, 2024, https://www.tudelft.nl/en/beyond-the-current.

[16] Jerzy Sowa, "Termomodernizacja i Unowocześnienie Budynków Użyteczności Publicznej," *Fundacja Poszanowania Energii*, n.d.

[17] Andrzej Wiszniewski, "Modernizacja Systemu Zasilania w Ciepło Budynków Mieszkalnych," *Fundacja Poszanowania Energii*, n.d.

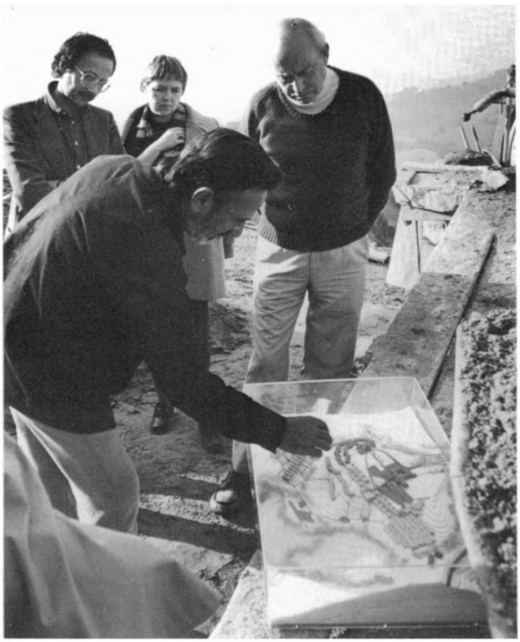

Fig. 3 Giancarlo de Carlo working with his team. (Perspecta, 1980)

Design Context

Grochowska tenement row.

A pattern can be observed along “Grochowska”, a prominent street in the “Grochów” section of Praga-Południe district in Warsaw. Long and short rows of residential townhouses are positioned along the avenue. They are strikingly similar to each other in their main topology as if having almost the same DNA, but through some phenotypical conditioning showing small variations from one to another. (Fig. 4).

In the Praga district, they were usually built to provide housing for incoming workers in the emerging industrial hub of right-bank Warsaw[18].

Shortly after the end of the 1st World War, Grochów as the biggest district, territory wise, had only 13% of its buildings made of brick, mostly single storey, which attributed to 90.7% of all residential building stock[19]. Only a few buildings had access to running water or sewage[20]. During the first half of inter-war period, much of Grochów was still like a *“Far-West”* of Warsaw, with vast slums for homeless people covering swampy regions[21]. But thanks to multiple stimulus plans, the district was developing fast, especially during

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[18] Aleksander Łupienko, “Kamienice Czynszowe Warszawy,” *Instytut Historii PAN* 1, no. 1 (2015), http://rcin.org.pl.

[19] Magistrat Miasta Stołecznego Warszawy, “Rocznik Wydziału Statystycznego Magistratu m. St. Warszawy. R. 1916,” *Centralna Biblioteka Statystyczna* (Warszawa: Magistrat m.st. Warszawy, 1919), 105–15, https://mbc.cyfrowemazowsze.pl/dlibra/publication/40241/edition/37638/content?format_id=2.

[20] Magistrat Miasta Stołecznego Warszawy, 111–13.

[21] Bruno Kiciński and Ludwik Adam Dmuszewski, “Grochów,” *Kurjer Warszawski : wydanie wieczorne. R. 109, 1929, nr 93*, April 6, 1929, 109, https://crispa.uw.edu.pl/object/files/213113/display/PDF.

1933-1939, when the Grochowska street got a hard surface makeover and over 80 town houses were built along the street[22]. Those townhouses were the first non-representational brick-and-mortar architecture in the area filled with otherwise dilapidated single-storey wooden huts and a chaotic mix of suburb-village dwellings scattered around rail-dominated landscape, fields and wetlands[23].

Fig. 4 Dataset of building facades along Grochowska. Adapted from Google Street View.

[22] Katarzyna Komar-Michalczyk, "Ku Nowoczesności - Rozwój Grochowa w Okresie Międzywojennym," *Kronika Warszawy* 1, no. 132 (2007): 27.

[23] "KRONIKA WARSZAWY," *KRONIKA WARSZAWY* 1, no. 132 (2007).

System Approach and revival potential.

Rows were formed by building the townhouses in batches or one after the other, possibly by the same construction teams and craftsmen, with general knowledge from the industry at the time about low-cost housing (Fig. 5).

Thus, the similarity between them. They were, unlike the common post-war big plate residential blocks, built not with a modular system in mind. I see, however, a potential to treat them as a family, or of the same building "species" at least. That family of buildings, importantly, is not exclusive to Grochowska Street, as I could observe rows of such buildings in other parts of Warsaw or even other cities in Poland (Fig. 7). In Warsaw alone, I was able to quantify that there are at least 150 buildings closely matching the same typology, and around 300 more that could be treated similarly. To achieve that, I followed a machine learning framework which deployed a foundation model (DINOv2 ViT-B/14)[24] to analyse a collected dataset of filtered buildings and retrieve those highly matching the Grochowska row typology. These buildings, among 176,859 others, fall into the more general "PL.N.MFH.01.Gen" building category of the European Episcope Tabula project (Polish small Multi Family housing, built before 1945), and constitute almost 870,000 family apartments. [25]

What they share, without doubt, is the sorry state most of them are in, while only 7% being modernized. In some places the insulation is non-existent, and bare brick is

[24] Maxime Oquab et al., "DINOv2: Learning Robust Visual Features without Supervision," April 14, 2023, https://arxiv.org/abs/2304.07193v2.

[25] Narodowa Agencja Poszanowania Energii SA, "Tabula - Polish Building Typology" (Warsaw, 2012), https://episcope.eu/fileadmin/tabula/public/docs/scientific/PL_TABULA_ScientificReport_NAPE.pdf.

exposed to the outside (Fig. 6). There is a need to properly revive and sufficiently futureproof them so that their energy efficiency adheres to or even surpasses upcoming regulations, with energy use reduction potential calculated to exceed 70%. [26]

As they share similar characteristics, I see a potential to do it at scale and in a systematic way so that most such buildings could benefit from the same set of guidelines. A similar approach, applied to post-war big-plate modular residential block complexes, enjoys a fair amount of academic and practice interest[27]. There seems to be, however, little effort put into the issue of the topical inter-war town houses.

Given that this mentioned system or framework would be based on biogenic material strategies, the new "clothes" for said buildings would not provide future generations with comfortable living environment but also fit into the natural carbon cycle of the biosphere. This potential to directly improve, even so slightly, the lives of so many people and contribute to more natural, biodegradable built environment, drives my work and ambitions.

How to get it right? Where to start?

[26] Narodowa Agencja Poszanowania Energii SA.

[27] Krzysztof Barnaś et al., "Algorithm for the Comprehensive Thermal Retrofit of Housing Stock Aided by Renewable Energy Supply: A Sustainable Case for Krakow," *Energy* 263 (January 15, 2023): 125774, https://doi.org/10.1016/J.ENERGY.2022.125774.

Fig. 5 Grochowska 281 during construction and Grochowska 283 just after completion. 1936. National Archive in Warsaw.

Fig. 6 Examples of deterioration, Grochowska 271,275, 283. (Google Street View, 2024)

Fig. 7 Townhouse rows in different cities. Adapted from Google Earth.

Problem

The will in young generation to push change is strong, however it struggles to bring the proven ideas to the general practice and future end users. It feels like young innovative architects and established practices operate in two quite separate worlds.

Bio-based materials come with challenges to be aware of. With fast paced innovation and discreteness of the industry, it is often difficult to find reliable data about their properties. Environmental Product Declarations (EPDs) might help with that, but only a small percentage of suppliers go that far. On the other note, eager and bold designers sometimes tend to forget for whom the architecture is that they propose. Focusing on innovation for the sake of it or individual aesthetic ideas that might help provide some media traction or an edge in competitions. It can happen that people are not entirely happy for the interventions, feeling uncomfortable or even unsafe in their own living environments after completion[28]. Or else, combined with younger well-off generations interest in novel “trendy” atmospheres, the same strategies that were supposed to help original, often energy impoverished users, gentrify the area and push them away from it[29].

While the broad theme of working with existing building stock gains increasing attention in both theory and practice[30], in

[28] Katrin Grossmann and Sandra Huning, “Energy-Efficient Retrofitting and Affordable Housing: Open Questions for Urban Research and Practice.,” 2015.

[29] Leo Oorschot and Thaleia Konstantinou, “Retrofit for Continuity! Sustainability and Gentrification of Tenement Apartment Blocks in Dutch Cities from Inter and Post War Period,” *Living and Sustainability*, 2017.

[30] Liliane Wong, “Adaptive Reuse : Extending the Lives of Buildings,” 2017, 256.

the wider Polish architectural discourse, especially in renovation, bio-based solutions are still considered a niche, experimental or somewhat fringe idea. In fact, building with bio-based materials remains challenging in other European countries. It is mostly due to strict regulations, limited availability, and widespread lack of knowledge [31] directed to laypeople in an accessible way. There is a will for renovation and the need for renewable material use, with a gap separating the two. While influencing regulations or increasing material availability is out of my power currently, I can at least contribute with knowledge dissemination.

[31] Joanna Hadley-Smith and Oliver Stainton, "Are Bio-Based Materials Suitable for Mainstream Construction?," Buro Happold, August 9, 2024, https://www.burohappold.com/news/are-bio-based-materials-suitable-for-mainstream-construction/.

Fig. 8 Adding Styrofoam insulation - Standard practice in Poland. (Murator.pl)[32]

Fig. 9 Insulating with straw - bio-based alternatives for futureproofing buildings[33]

[32] "Jak Obliczyć, Ile Potrzeba Styropianu Na Ocieplenie Domu i Jaki to Będzie Koszt? - Murator.Pl," accessed October 22, 2024, https://muratordom.pl/budowa/elewacja/jak-obliczyc-ile-potrzeba-styropianu-na-ocieplenie-domu-i-jaki-to-bedzie-koszt-kalkulator-aa-cxka-GNWr-uSwt.html.

[33] "Haus P&W | 0451_Casa_Steil_Mar," accessed October 22, 2024, https://www.atelierschmidt.ch/sanierung-susch?pgid=jdue1rbe-7744018c-ef24-464c-bdc6-79566148255b.

Question

How can we bridge that gap then? My observation and thesis are that a simple guidebook or booklet of bio-based renovation solutions could be of much help. During the design stage, I would like to explore the potentials for bio-based materials use in the Polish context, evaluating how such a readily available guidebook can help the innovation be more approachable and improve user adoption of biogenic solutions for futureproofing in general.

But first, such a custom resource must be developed, and how to do it right is a question in of itself. What aspects need to be taken care of, what material parameters are the most important, what are the general principles in masonry refurbishment works? Additionally, I am concerned with the users - people for whom the bio-based innovation is meant. What are their needs and priorities regarding refurbishment, and consequently - how bio-based solutions fit into all those requirements.

→ **Main Question**
  - How to integrate bio-based solutions in masonry building retrofitting, considering both technical requirements and user preferences?

→ **Sub-Questions** – Technicalities, User-Centric Design, Knowledge Dissemination
  - What are the technical requirements while futureproofing masonry buildings?
  - What are the user needs and priorities in transition towards biobased futureproofing?
  - How can an accessible knowledge base of biobased refurbishment strategies help advance their adoption rate?

Literature Review

The research outcomes have the potential to fill out the knowledge gap that exists in the Polish renovation practice regarding readily available and promising bio-based solutions for masonry brick buildings renovation. It could help make bio-based options more approachable and trustworthy from conservative designers' and homeowners' perspectives. Guidebook/ catalogue-like form of publication could also serve as a helpful resource for students. Moreover, it can, by a large amount, be applied also to newly built bio-based architecture, which broadens the scope of potential influence. Similar resources exist in the context of USA, Nordic or some western European countries, providing useful information on refurbishment practices and environmental impact of materials [34] (Fig. 10), though rarely combining the two. While information found on manufacturers websites can be too technical for a homeowner in search for general information [35].

Currently existing resources available for laypeople can be divided into two groups in my opinion. The first one provides useful guidance on general refurbishment or energy retrofit options for various types of buildings, however, focusing on the logistic and financial side. Examples include tips on seeking funding, or types of interventions that will make the retrofit more financially attractive as an investment [36]. Those

[34] "Unboxing Carbon | Henning Larsen," accessed December 19, 2024, https://henninglarsen.com/projects/unboxing-carbon.

[35] "Application Range for Cellulose Insulation: Facade - ISOCELL | ISOCELL," accessed December 13, 2024, https://www.isocell.com/en/cellulose-insulation/solutions-and-application-areas/wall/facade.

[36] Dariusz Śmiechowski, "NADBUDOWA BUDYNKÓW WIELORODZINNYCH," *Fundacja Poszanowania Energii*, n.d., accessed October 14, 2024.

guides can be useful, but they do not introduce technical aspects, leaving them to hired, hopefully competent designers or contractors, meaning that homeowners may not be able to differentiate between good and bad practice [37].

Another group includes guides that provide more technical knowledge about refurbishment and building science, also regarding masonry buildings [38]. Information on possible interventions, insulation and moisture management challenges can be found easily and in accessible form. However, on the material side and thus specific buildup construction options, it is almost impossible to find any information about biogenic alternatives to conservative practice dominated by oil-based styrofoam or mineral wool [39]. The situation is different and more optimistic in the western and northern Europe, with a large body of research and work put into refurbishment topic, from general guidebooks to more complex toolboxes, including biogenic materials [40]. Polish homeowners considering retrofitting, on the other hand, will simply not be introduced to renewable, low embodied carbon strategies while looking for information on what they could do to improve their buildings.

[37] Sowa, "Termomodernizacja i Unowocześnienie Budynków Użyteczności Publicznej."

[38] "Jak Ocieplić Ścianę z Cegły: Remont Starego Domu - Murator.Pl," accessed December 13, 2024, https://muratordom.pl/remont-domu/termomodernizacja/jak-ocieplic-sciane-z-cegly-remont-starego-domu-aa-wHSY-1xxj-5YLg.html.

[39] "Jak Przeprowadzić Ocieplenie Starego Domu - Jakich Użyć Materiałów? - Ładny Dom - Remont Domu," accessed December 13, 2024, https://ladnydom.pl/ocieplamy-stare-sciany.

[40] Thaleia Konstantinou, "Facade Refurbishment Toolbox: Supporting the Design of Residential Energy Upgrades," *A+BE | Architecture and the Built Environment* 4, no. 9 (July 5, 2014): 1–420, https://doi.org/10.7480/abe.2014.9.660.

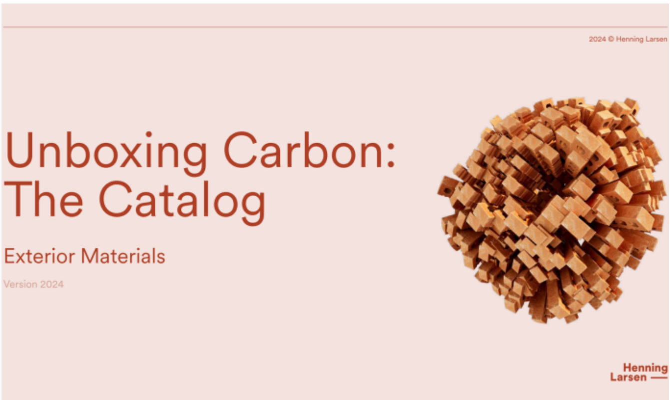

Fig. 10 The "Unboxing Carbon" Catalog provides information on selected materials and their environmental impact. (Henning Larsen, 2024)

Methods

Literature research and Case Studies

Literature research formed the foundation of my work. It included academic papers, reports, guidebooks, professional publications, online video content, and other sources. I remained cautious about biases and private interests, particularly in non-academic materials. For bio-based materials and solutions in Poland and Eastern Europe, I reviewed academic and published works on established and emerging technologies. This research also provided insights into user priorities for refurbishment practices and analysed accounts from individuals whose spaces were improved with bio-based materials. It highlighted what people value in futureproofing, focusing on their short- and long-term needs.

Market research and guidebook creation

Market research formed the basis for the catalogue. I explored what's available in the current setting and what might gain market viability soon. The metrics and parameters for the catalogue were defined first through research on what's important in refurbishment practice and what do occupants care about and secondly based on existing similar catalogues [41]. Those are filled for each entry in the catalogue, and include: Embodied Energy, Global Warming Potential A1-A3, Thermal Conductivity, etc. As I reflected with my veduta while starting the research (Fig. 11), my general interests lay in cataloguing, curation, and

[41] Magdalena Zabek, Thaleia Konstantinou, and Tillmann Klein, "D2.3. Sustainable Requirements," *Zenodo*, 2023, https://doi.org/10.5281/ZENODO.8239083.

data analysis for further use in design process. I prepare building blocks first, design later.

Interviews

In support to literature research, I interviewed familiar researchers and practitioners, as well as municipality board members specialising in urban, architecture design and biogenic materials for construction. Interviews helped to contrast research with a local reality, especially regarding adoption rate of biobased materials, source of funding or lack of action from homeowners and the city itself. All of them gave insights which helped refine the outcome of the research for the target audience and define which bio-based solutions have less or more ground for success specifically in my design project.

Interviews were thoroughly planned, with a set of questions prepared beforehand. Permission for paraphrasing gained answers in publication was granted by interviewees.

Fig. 11 Veduta showing my initial fascination with collection and curating data into information and knowledge.

Results

How to navigate the technical requirements

Renovating and futureproofing inter-war Polish masonry townhouses requires a holistic approach that balances structural integrity, energy efficiency, and historical preservation. Effective strategies involve addressing moisture management, thermal performance, and modernizing installations while considering original architectural features. By combining these methods with an inclusive decision-making process, these buildings can be adapted to modern standards, ensuring resilience to climate challenges and enhancing the comfort of their residents.

Regulatory Compliance

Ensuring that retrofitting and futureproofing measures comply with current building codes and/or more strict ecological standards is crucial for long-term durability and safety of masonry town houses. In Poland, the current required U-value for walls is 0.20, and according to stricter NF-40 standard it should be even lower at 0.15 [42]. Buildings from 1918-1939 often fail to meet current energy standards and need urgent retrofitting, while without financial aid, achieving significant CO2 emission reductions resulting out of that may be challenging [43]. Renovation should balance

[42] Minister Rozwoju i Technologii, "Obwieszczenie Ministra Rozwoju i Technologii z Dnia 15 Kwietnia 2022 r. w Sprawie Ogłoszenia Jednolitego Tekstu Rozporządzenia Ministra Infrastruktury w Sprawie Warunków Technicznych, Jakim Powinny Odpowiadać Budynki i Ich Usytuowanie" (2022), https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20220001225.

[43] Adam Turecki et al., "Renovation of Modernist Housing Developments in the Pursuit of Modernity for Well-Being and Clean Energy," *Energies*

regulatory compliance with preservation of historical value and architectural features, which often comes with interesting challenges.

Energy Efficiency

The main reason to refurbish and futureproof buildings is improving their energy efficiency, making occupant lives cheaper and more comfortable. Most inter-war tenement houses have insufficient thermal insulation and moisture protection. Modernisation should include general improvement of walls, windows, roofs and floor slabs for a comprehensive thermal refurbishment, not only insulation, and it can involve strengthening or replacement of timber and steel elements. Low performing roof can be replaced with additional usable living space as an extra floor. To further reduce energy demands and resulting carbon emissions, passive strategies can be applied, like introducing shading elements, adding a second façade with new usable space, or removing obstacles where solar radiation is beneficial [44].

2022, Vol. 15, Page 3737 15, no. 10 (May 19, 2022): 3737, https://doi.org/10.3390/EN15103737.

[44] Lukas Lång and Efraim Sandgren, "Renovation of Brick Buildings Constructed 1870--1930 Investigation of the Thermal Envelope in Renovated and Re--renovated Dwellings" (CHALMERS UNIVERSITY OF TECHNOLOGY, 2016).

Structural Integrity

Before any work can be done, the stability of exterior load-bearing brick masonry walls, floor slabs and foundations must be ensured. Structural issues can lead to significant consequences if not properly addressed from the start. Retrofitting should be approached cautiously with expert knowledge, especially for timber elements like roof or floor beams, to avoid compromising buildings technical condition [45].

Moisture Management

Probably the most critical issue while dealing with old masonry buildings is proper moisture management, suboptimal interventions can lead to serious deterioration of brick and other materials due to mold, fungi, or efflorescence. Understanding the hygrothermal behaviour of brick walls is crucial. Factors such as thermal conductivity and moisture content of bricks and insulation significantly impact the building's resilience to moisture. Solutions that limit precipitation uptake or increase the drying-out rate, combined with proper maintenance of moisture control systems, including intact roofs, gutters, and foundation drainage are helpful to prevent future deterioration. Adding insulation to brick buildings can increase the risk of moisture accumulation, especially in case of suboptimal internal insulation works, leading to mold growth and material decay. The walls should be able to dry out easily. Insulation materials have varying performance under current and

[45] Ibrahim Erdem and David B. Peraza, "Challenges in Renovation of Vintage Buildings," *Journal of Performance of Constructed Facilities* 29, no. 6 (December 25, 2015): 04014166, https://doi.org/10.1061/(ASCE)CF.1943-5509.0000666/ASSET/9E7E3A44-07DF-4EDC-8E9D-74661B30F97B/ASSETS/IMAGES/LARGE/FIGURE6.JPG.

future climate scenarios, and natural "traditional" options like wood fibre, cellulose or hemp are proved to work well with masonry [46].

Building Services

Implementing modernized heating and cooling building services can significantly improve user comfort and building energy efficiency. Many tenement houses from the inter-war period lack modern water or sewage services. Refurbishment should take that into account and implement piping replacement and whole system enhancement. Basic electricity and natural gas access handled in a safe manner is a baseline consideration in cases where more modern or ecological services cannot be applied [47]. When possible, current best practice solutions should be considered, including installation of solar hot water, photovoltaic panels, heat pumps, or Trombe walls.

User Comfort

Crucial element of a building, often overlooked, are its users and their comfort. Apart from addressing thermal, acoustic, and aesthetic comfort through optimized technical measures and careful material choices, it is worth considering the personal needs and expectations of residents so that modernization contributes to improving both the quality of life and possibly strengthening the sense

[46] Jacqueline Lu et al., "Climate Resilience of Internally-Insulated Historic Masonry Assemblies: Comparison of Moisture Risk under Current and Future Climate Scenarios," *Minerals 2021, Vol. 11, Page 271* 11, no. 3 (March 6, 2021): 271, https://doi.org/10.3390/MIN11030271.

[47] Klara Kroftova and Radek Zigler, "Building and Architectural Details of Tenement Houses Built at the Turn of the 19th and 20th Centuries in Central European Region—Hygrothermal Analysis," *Buildings 2023, Vol. 13, Page 451* 13, no. 2 (February 7, 2023): 451, https://doi.org/10.3390/BUILDINGS13020451.

of community [48]. More insights can be found in the "How to include user needs in futureproofing" section.

Authenticity

Refurbishment of old housing stock will always come with questions regarding heritage and authenticity. Oftentimes preservation measures will already be included in local regulations, but even if it's not the case, everybody should be wary of architectural values. Depending on circumstances and subjective assessment, it is important to maintain the look and feel of the original architectural design, focusing on historical authenticity and maximum utility while preserving the original design's aesthetic. The exact measures might vary, from careful material choices to attention to details like decorative elements on facades, windows or doors, which represent important cultural heritage [49].

[48] Małgorzata Fedorczak-Cisak et al., "Measurement and Diagnosis of Comfort in a Historic Building," *Energies 2022, Vol. 15, Page 8963* 15, no. 23 (November 27, 2022): 8963, https://doi.org/10.3390/EN15238963.

[49] Kroftova and Zigler, "Building and Architectural Details of Tenement Houses Built at the Turn of the 19th and 20th Centuries in Central European Region—Hygrothermal Analysis."

How to include user needs in futureproofing

Renovating the built environment is a complex multi objective challenge where not only technical aspects have to be considered but also the various needs of current and future occupants. They have to be included as much as possible from the very beginning, to ensure long term success of the intervention.

Energy Efficiency

Improving the thermal insulation and replacing windows are common interventions that can significantly reduce energy demand and are the first to be considered by occupants. However, their behaviour, such as habits related to improper use of heating/cooling systems and lighting, can impact the effectiveness of these measures. Without proper education renovation measures can be nullified, thus they should come with operational guidance or be aligned with occupant preferences if possible [50].

Economics

By far the most important factor shaping homeowners' decisions regarding refurbishment still is its economics [51]. Apart from the base cost of materials, economic considerations such as cost savings from energy efficiency

[50] Fabrizio Ascione et al., "The Role of the Occupant Behavior in Affecting the Feasibility of Energy Refurbishment of Residential Buildings: Typical Effective Retrofits Compromised by Typical Wrong Habits," *Energy and Buildings* 223 (September 15, 2020): 110217, https://doi.org/10.1016/J.ENBUILD.2020.110217.

[51] Slawomir Czarnecki and Marlena Rudner, "Recycling of Materials from Renovation and Demolition of Building Structures in the Spirit of Sustainable Material Engineering," *Buildings 2023, Vol. 13, Page 1842* 13, no. 7 (July 21, 2023): 1842, https://doi.org/10.3390/BUILDINGS13071842.

and potential subsidies or grants, are also crucial to consider. Investors need to understand both environmental and economic benefits of different material choices on various stages to make informed decisions [52]. Optimal choice of strategies and materials involves a multi criteria approach in most cases, where economic factors are put in parallel with their environmental impact referring to embodied and operational energy or global warming potential, and influence on human health and comfort. These soft factors, often not obvious from the beginning, might alter the economics of the interventions through subsidies or other grants, resulting in an ecological strategy being more economical than a traditional carbon intensive one, even though it might be more costly upfront [53].

Agency

The user must feel that a building is tailored to his existence and allows for comfortable symbiosis, even more so that he had control over the choices made. Designing buildings with a focus on occupants' preferences and behaviours can address gaps in comfort and operational efficiency. It should involve both real occupant inclusion in the design process, having in mind their educated preferences, and using data-

[52] Mario Sobolewski, "Building Refurbishments from the Perspective of Economic Efficiency in the Selection of Materials, Based on the Method of Paired Comparison and Benefit Analysis," *International Journal of Innovative Technology and Exploring Engineering* 13, no. 1 (December 30, 2023): 39–46, https://doi.org/10.35940/IJITEE.A9764.1213123.

[53] J. K. Kaltenegger et al., "ROTUNDORO: A Web-Based Decision Support Prototype for Housing Refurbishments Considering Consumer Preferences," *IOP Conference Series: Earth and Environmental Science* 1085, no. 1 (September 1, 2022): 012022, https://doi.org/10.1088/1755-1315/1085/1/012022.

driven occupant modelling strategies [54]. Everyone is different and a building can change its occupants over time, thus it should also be adaptable. Designing housing that can accommodate small future changes will help avoid premature end of its life. People treat space and things with more care and feel more attached to reality they had control over. To further boost agency in operation phase, providing inhabitants with instructions for self-renovation and repair, knowing which materials were used, what to watch out for and how to care for them, can empower them to make sustainable choices and improve their living standards [55].

Healthy, Aesthetic and Comfortable Living

Users prioritize materials that offer visual appeal, durability, and ease of maintenance. Less visible yet still highly influencing users lives and health is material composition and VOC (Volatile Organic Compound) content. A right choice of finishing and insulating materials will influence humidity of the interior or radiative warmth of the surfaces. Using low VOC paints and ensuring proper ventilation can also enhance indoor air quality, improving comfort and health of residents [56]. Right choice of materials will also improve daylight conditions, reduce glare effects, providing visual comfort, which is related to human health. It can

[54] William O'Brien et al., "Introducing IEA EBC Annex 79: Key Challenges and Opportunities in the Field of Occupant-Centric Building Design and Operation," *Building and Environment* 178 (July 1, 2020): 106738, https://doi.org/10.1016/J.BUILDENV.2020.106738.

[55] Coline Senior et al., "The Spirit of Time—The Art of Self-Renovation to Improve Indoor Environment in Cultural Heritage Buildings," *Energies 2021, Vol. 14, Page 4056* 14, no. 13 (July 5, 2021): 4056, https://doi.org/10.3390/EN14134056.

[56] Yani Rahmawati et al., "Environmental Enhancement through High-Rise Building Refurbishment," *Sustainability 2020, Vol. 12, Page 9350* 12, no. 22 (November 11, 2020): 9350, https://doi.org/10.3390/SU12229350.

further reduce the need for artificial lighting and thus energy demand [57].

Community, Accessibility and Inclusion

The society is aging and that's especially the case for older not yet refurbished buildings nowadays, where accessibility is challenging due to lack of an elevator or other aids. Renovation strategies should consider the needs of an ageing society, such as improving accessibility and supporting assisted living models, which can provide better comfort or be more cost-effective than institutional care [58]. Apart from elderly, it is also important to accommodate neurodiverse populations, such as autistic individuals, which involves the use of simple spatial layouts, and managing sensory stimuli (e.g., dimmable lighting, sound insulation, natural simple colours) [59].

Additionally, promoting a social mix through trans-generational housing, instead of replacing housing demographics as it often happens, can enhance the long-lasting social sustainability of refurbishment projects [60].

[57] Pilar Mercader-Moyano, Paula M. Esquivias, and Radu Muntean, "Eco-Efficient Analysis of a Refurbishment Proposal for a Social Housing," *Sustainability 2020, Vol. 12, Page 6725* 12, no. 17 (August 19, 2020): 6725, https://doi.org/10.3390/SU12176725.

[58] Iva Kovacic, Markus Summer, and Christoph Achammer, "Strategies of Building Stock Renovation for Ageing Society," *Journal of Cleaner Production* 88 (February 1, 2015): 349–57, https://doi.org/10.1016/J.JCLEPRO.2014.04.080.

[59] Melissa Heather Black et al., "Considerations of the Built Environment for Autistic Individuals: A Review of the Literature," *Autism* 26, no. 8 (November 1, 2022): 1904–15, https://doi.org/10.1177/13623613221102753/ASSET/IMAGES/LARGE/10.1177_13623613221102753-FIG1.JPEG.

[60] Kovacic, Summer, and Achammer, "Strategies of Building Stock Renovation for Ageing Society."

Contribution to Sustainability

While still considered very low priority in Eastern European context [61], climate impact of materials can (and should) increase in relevance for current and upcoming generations. In other parts of western and northern Europe, especially Nordic countries, there is a significant preference for materials that contribute to environmental sustainability [62]. Material preferences can be influenced by cultural backgrounds and experiences of individual societies or individuals themselves. While in Sweden or Norway wood is valued, in Poland it is considered unsafe and expensive compared to established concrete or silicate products. Lack of subsidies and significant base price difference does not help to consider ecological alternatives. If a material is to be considered as environmentally friendly, then it is valued by future users for it to be certified properly, however other factors like price and durability are still far more important. [63]

[61] Czarnecki and Rudner, "Recycling of Materials from Renovation and Demolition of Building Structures in the Spirit of Sustainable Material Engineering."

[62] Anders Roos et al., "Impact of Prospective Residents' Dwelling Requirements on Preferences for House Construction Materials," *Wood Material Science & Engineering* 18, no. 4 (July 4, 2023): 1275–84, https://doi.org/10.1080/17480272.2022.2126947.

[63] Yasushi Shoji et al., "Preferences for Certified Forest Products in Japan: A Case Study on Interior Materials," *Forest Policy and Economics* 43 (June 1, 2014): 1–9, https://doi.org/10.1016/J.FORPOL.2014.03.001.

How bio-based materials fit the needs.

Biobased materials, especially the ones from fast-growing crops, can contribute significantly to carbon storage for at least the service life of the building, assuming new plants are grown in their place. The energy required for their production is usually lower than traditional non-organic alternatives, they are biodegradable in majority of cases or can be safely combusted as biofuel, staying within the natural biosphere carbon balance.

Biobased materials have a potential to clean the interior air, and can better regulate structure and indoor air humidity as well. They look and feel more welcoming and aesthetically pleasing, which all leads to a more comfortable living environment and better well-being of occupants.

Materials worth considering from the start for refurbishment in the central-easter European context:

→ Wood and Wood fibre – Structural wood has considerable carbon storage properties but is not quickly renewable [64]. Wood fibre is already established on the market as a great insulation product in many forms, mostly created from timber industry by-products.

→ Bio-Bricks and Hybrid Bricks - Bio-bricks made from agro-waste or biologically cemented sandstone can have a negative carbon footprint [65]. Hybrid bricks made from natural fibres and waste materials (e.g., coconut waste fibre, wheat straw fibre) apart from ecological,

[64] Verena Göswein et al., "Land Availability in Europe for a Radical Shift toward Bio-Based Construction," *Sustainable Cities and Society* 70 (July 1, 2021): 102929, https://doi.org/10.1016/J.SCS.2021.102929.

[65] Priyabrata Rautray et al., "Bio-Brick - Development of Sustainable and Cost Effective Building Material," *Proceedings of the Design Society: International Conference on Engineering Design* 1, no. 1 (2019): 3171–80, https://doi.org/10.1017/DSI.2019.324.

thermal and acoustic insulation benefits are also a great architectural fit for masonry buildings [66].

→ Straw - Straw processed in a modern way has insulation properties close to market standards. It has a high potential for carbon storage, making it effective in reducing carbon emissions when used as insulation [67].

→ Hemp and Flax - Hemp and Flax fibre insulation is effective for retrofitting, providing good hygrothermal performance also as interior insulator [68]. Hemp chips can be used in hempcrete or "LimeHemp" as load bearing or wall filling substrate exhibiting great thermal performance, carbon storage and air cleaning properties. Easily available in Poland with existing market.

→ Cellulose - Loose-fill cellulose insulation can be effective for breathable insulation without the need for a vapor barrier, although moisture management is crucial [69].

[66] Tala Moussa et al., "Spent Coffee Grounds as Building Material for Non-Load-Bearing Structures," *Materials 2022, Vol. 15, Page 1689* 15, no. 5 (February 24, 2022): 1689, https://doi.org/10.3390/MA15051689.

[67] Francesco Pittau et al., "Retrofit as a Carbon Sink: The Carbon Storage Potentials of the EU Housing Stock," *Journal of Cleaner Production* 214 (March 20, 2019): 365–76, https://doi.org/10.1016/J.JCLEPRO.2018.12.304.

[68] Carsten Rode et al., "Performance of Bio-Based Products for Interior Insulation of Solid Masonry Walls," *Journal of Physics: Conference Series* 2654, no. 1 (December 1, 2023): 012082, https://doi.org/10.1088/1742-6596/2654/1/012082.

[69] Rode et al.

Materials more experimental or less local to the Polish context:

- → Seaweed or Eelgrass used as insulation or sound proofing boards.
- → Mycelium as a bonding for substrates interesting for interior elements production.
- → Various agro/food-waste composites like tiles from coffee grounds or fruit pectin.
- → Cork - It has significant carbon storage potential. It's an interesting option but requires quite some transportation from southern countries, is not quickly renewable, and thus more local materials might be more beneficial [70].

While not necessarily biobased, modular and prefabricated wall systems are promising to scale circular futureproofing, possibly combined with waste streams from local demolition sites [71].

[70] Göswein et al., "Land Availability in Europe for a Radical Shift toward Bio-Based Construction."

[71] Ravijanya Chippagiri et al., "Application of Sustainable Prefabricated Wall Technology for Energy Efficient Social Housing," *Sustainability 2021* 13, no. 3 (January 23, 2021): 1195, https://doi.org/10.3390/SU13031195.

Fig. 12 A collection of biogenic materials. (Rasmus Hjortshøj, 2023)

How can a guidebook and catalogue of biogenic materials help the transition

A guidebook of possible renovation strategies and an easily available catalogue of sustainable materials empowers homeowners, designers and policymakers to make environmentally responsible choices during building refurbishments. By providing comprehensive LCA (Life Cycle Assessment) data, material comparisons, and promoting resource-efficient and locally sourced materials, such a catalogue can significantly reduce the environmental impact of refurbishments while also offering health benefits.

Informed Decision-Making

A catalogue can provide, apart from basic properties, certified LCA data like GWP (Global Warming Potential), helping homeowners understand the environmental impacts of different materials over their entire life cycle, from production to disposal [72]. As such data, usually retrieved from EPDs (Environmental Product Declarations) does not always include calculations for disposal, or at best only assumes those, it might be better to include only the impact and emissions from A1-A3 phases of manufacturing, before transport. Either way it could expose all involved to the positive benefits of low embodied carbon use in refurbishment. [73]

[72] Bernardette Soust-Verdaguer, José Antonio Gutiérrez, and Carmen Llatas, "Development of a Plug-In to Support Sustainability Assessment in the Decision-Making of a Building Envelope Refurbishment," *Buildings 2023, Vol. 13, Page 1472* 13, no. 6 (June 6, 2023): 1472, https://doi.org/10.3390/BUILDINGS13061472.

[73] Mercader-Moyano, Esquivias, and Muntean, "Eco-Efficient Analysis of a Refurbishment Proposal for a Social Housing."

Often it can happen that homeowners faced with renovation of their building do not have much time and mental capacity left to consider and research all the new healthier alternatives to what is already available on the market. Thus, going for the easiest options proposed by a local craftsman who are possibly bound by industry standards and lobby. Having an accessible catalogue at their disposal, homeowners can compare conventional materials with sustainable alternatives, such as recycled paper-based facades versus expanded polystyrene (EPS), to make more eco-friendly choices.

A catalogue, built from a database, could easily be implemented early in the design process, exactly when the biggest most impactful changes are possible. This would benefit the designers most. Tools like BIM plug-ins can integrate sustainable material choices in the preliminary concept design stages, ensuring that ecological considerations are factored into the refurbishment from the start [74].

Environmental Impact Reduction

A crucial purpose of the catalogue is to increase the positive impact of higher biogenic materials adoption. The catalogue can include options for using local and traditional materials, which often have lower environmental impacts due to reduced transportation and processing needs [75]. Added benefit of that is their expected increased longevity and

[74] Soust-Verdaguer, Gutiérrez, and Llatas, "Development of a Plug-In to Support Sustainability Assessment in the Decision-Making of a Building Envelope Refurbishment."

[75] Camilla Mileto et al., "A Sustainable Approach for the Refurbishment Process of Vernacular Heritage: The Sesga House Case Study (Valencia, Spain)," *Sustainability (Switzerland)* 13, no. 17 (September 1, 2021): 9800, https://doi.org/10.3390/SU13179800/S1.

predictability as in all native plant species. Using sustainable biogenic materials can reduce the consumption of natural resources and lower greenhouse gas emissions, contributing to the decarbonization of the building sector. While the benefits from refurbishment in the operational building impact are comparable between bio-based and traditional materials, the former highly outweigh the latter in terms of embodied emissions reduction [76].

The catalogue can also highlight materials or reclaimed building elements from local waste streams that promote waste reduction through recycling and reuse, which can significantly lower the environmental impact of refurbishments [77]. This however assumes a connection of a catalogue to a local network of demolition recycling efforts, and a certain rate of standardisation of said reclaimed materials and composites.[78]

[76] Stefan Sattler and Doris Österreicher, "Assessment of Sustainable Construction Measures in Building Refurbishment—Life Cycle Comparison of Conventional and Multi-Active Façade Systems in a Social Housing Complex," *Sustainability 2019, Vol. 11, Page 4487* 11, no. 16 (August 19, 2019): 4487, https://doi.org/10.3390/SU11164487.

[77] Agneta Ghose, Massimo Pizzol, and Sarah J. McLaren, "Consequential LCA Modelling of Building Refurbishment in New Zealand- an Evaluation of Resource and Waste Management Scenarios," *Journal of Cleaner Production* 165 (November 1, 2017): 119–33, https://doi.org/10.1016/J.JCLEPRO.2017.07.099.

[78] Czarnecki and Rudner, "Recycling of Materials from Renovation and Demolition of Building Structures in the Spirit of Sustainable Material Engineering."

Long term Health Benefits

Refurbished homes using sustainable materials can enhance the health and well-being of occupants by improving indoor air quality and overall living conditions, as those in most cases exhibit lower to non-VOC contents [79]. Organic materials can be adopted more easily when users of the catalogue are exposed to their benefits for human health early in the process. They are often not aware of healthier alternatives.

[79] Vishnupriya Narayanan et al., "Comparative Assessment of Insulation Materials for Improving Indoor Air Quality in Building Retrofit," *Environmental Science & Sustainable Development* 9, no. 2 (July 1, 2024): 34–47, https://doi.org/10.21625/ESSD.V9I2.1071.

The Guidebook and the Catalogue

Research conducted while answering the questions informed the contents of the guidebook and the accompanying booklet of biobased materials. The main purpose of those documents is introducing possible actions one can take to improve wellbeing of a masonry building, and how renewable bio-based materials can be used to achieve that goal – to further rise awareness about them.

The Guidebook (Fig. 13) contains basic and most important information on various strategies that can be taken to improve the performance of a masonry multifamily housing. Those include possible interventions for buildings walls, roofs, floors etc. and issues that might emerge, especially when working with mass brick walls, including moisture problems or taking advantage of thermal mass effects. For each strategy there are suggestions on which renewable materials can be suitable to optimise their positive effects. Complimentary to the guidebook, a Catalogue of biobased materials was prepared (Fig. 14), presenting examples of products suitable for insulation, structure, or finishings. Each material has it's GWP A1-A3 (total Global Warming Potential in A1-A3 phases based on EPD data), and other most important parameters listed. So far priority was given to materials available in Eastern European context.

I imagine that the outcome could be built upon later and evolve over time in a crowd source manner to benefit from updated data and continue its viability into the future. The documents will be available in both English and Polish language.

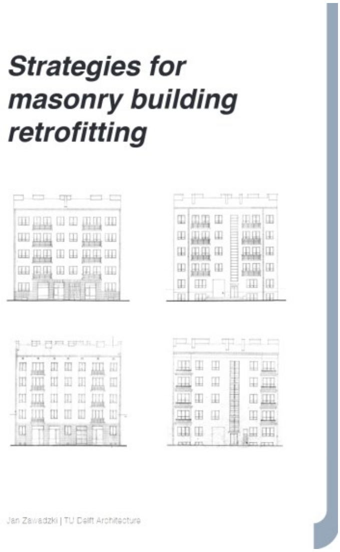

Fig. 13 Guidebook on Strategies for masonry building retrofitting. (Jan Zawadzki, 2025)

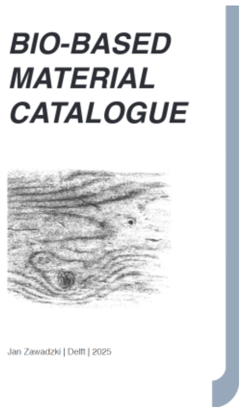

Fig. 14 Catalogue of Bio-Based Materials. (Jan Zawadzki, 2025)

Conclusions

This work demonstrates that bio-based materials can play a significant role in retrofitting Polish inter-war masonry buildings, addressing both decarbonisation and practical needs. The study shows that effective futureproofing requires solutions that improve energy efficiency, manage moisture effectively, and maintain structural stability, all while respecting the potential historical character of these buildings. Materials such as hemp, flax, wood fibre, and straw offer strong potential due to their low or negative carbon footprint, local availability, and high compatibility with brickwork structures.

User preferences were found to be strongly influenced by cost, certified quality, comfort, and the ability to maintain or adapt their living spaces. Bio-based solutions address these aspects by improving indoor conditions, being safer for health, and aligning with user expectations for quality and aesthetics. However, ensuring these benefits are clearly communicated to homeowners and designers is key to increasing adoption.

The research also highlights the importance of accessible knowledge resources, such as a guidebook and materials catalogue. By providing clear information on bio-based options and their benefits, these tools can help bridge the gap between innovative ideas and practical application. This study contributes to the growing body of knowledge on renewable retrofitting and futureproofing, offering insights for future projects that aim to combine environmental responsibility with user-centred design.

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