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Fraunhofer Institute for Building Physics IBP

Research, development, demonstration and consulting in all areas of building physics

Approval of new construction materials, components and design methods

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Overview of sustainable building materials and their possible applications – Part 2- Recycling materials

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Content

1 Introduction

Within the REBUMAT project, AP3 will provide an overview of sustainable materials, bio-based renewable materials and recycled materials. WP5 calls for proposals for possible recycling solutions and implementations in Vietnam. This paper will first give an overview of recycled materials (Part 2) and list suggestions and ideas for implementation in Vietnam.

2 Recycling materials used in Germany and in Europe

Recycled materials, known as recyclates, are increasingly integral to the construction sector in Germany and across Europe, driven by environmental concerns and resource efficiency goals. In Germany, the construction industry generates approximately 220 million tons of waste annually. A significant portion of this is repurposed into new building projects, exemplified by initiatives like Germany's first recycling house in Hanover, constructed in 2019 using entirely reusable materials [1]. Across the European Union, the construction sector is responsible for nearly 40 % of emissions and about a third of all waste produced. However, only around 40 % of construction waste is currently recycled or reused, often relegated to secondary applications rather than new builds. Adopting a circular approach in construction holds significant potential for environmental, social, and economic benefits. [2] Despite advancements, several challenges hinder the widespread adoption of recyclates in construction. The main problem is the quality perception; recycled materials are often perceived as inferior to primary materials, despite meeting the same standards. Enhancing quality control and education can improve acceptance [3]. The second challenge are economic factors; volatile raw material prices, high inflation, and disrupted supply chains add financial strain to construction projects, complicating the integration of recycled materials [4]. The European Union aims to double the circular material use rate by 2030. As of 2021, 11.7 % of all materials used in the EU-27 were sourced from recycled waste, up from 8.3 % in 2004. However, at the current pace, the EU is not on track to meet this target, indicating a need for more ambitious strategies [5]. Innovative projects are paving the way for increased use of recyclates. For instance, the Circ-Boost project is developing recycled concrete and mapping tools to facilitate circular construction practices across Europe [6]. In Germany, platforms like restado.de serve as marketplaces for reclaimed construction materials, offering over a million items valued at more than EUR 40 million, thereby promoting the reuse of materials in both private and professional projects [7]. To achieve higher circularity, the construction sector must embrace innovative recycling processes, improve perceptions of recycled materials, and implement supportive policies. Collaborative efforts among industry stakeholders, policymakers, and researchers are essential to overcome existing challenges and fully realize the potential of recyclates in construction [8], [9].

3 Recycling materials used in Asia und Vietnam

The integration of recycled materials, or recyclates, in the construction sector is gaining momentum across Asia, including Vietnam, as part of broader efforts to promote sustainability and resource efficiency. In various Asian countries, initiatives are underway to incorporate recycled materials into construction practices. For instance, Singapore's Sustainable Construction Master Plan, launched in 2008, emphasizes efficient design to optimize the use of natural materials and promotes waste minimization, reuse, and recycling. The plan aims to reduce reliance on natural building materials and encourages the adoption of sustainable materials in the built environment [10]. In Taiwan, companies like Miniwiz and LOTOS are innovatively repurposing waste materials into high-performance building products. Miniwiz converts materials such as insect shells, rice husks, and plastic waste into durable building components, addressing the carbon footprint of the construction industry. LOTOS focuses on extending the life of concrete through products like natural stucco made from dredged silt and concrete substitutes using industrial waste [11]. In Vietnam, the construction industry is exploring the use of recycled materials to enhance sustainability. This ReBuMat project, for example, investigates how the sector can reduce its high level of resource consumption and share of global carbon emissions by using and reusing bio-based and recycled building materials [12]. Recycling construction and demolition waste (CDW) is identified as a viable approach to produce unburnt bricks, recycled concrete, and other building materials, thereby alleviating the demand for virgin resources. This circular economy approach not only offers environmental benefits but also economic opportunities by reducing raw material import costs and generating jobs in recycling and waste management [13]. Several challenges impede the widespread adoption of recycled materials in Vietnam's construction sector. One is the lack of standards; the absence of national standards and specifications for testing and acceptance of recycled materials makes their use in construction projects challenging [14]. There is a need to enhance awareness and change perceptions regarding the quality and applicability of recycled materials among stakeholders in the construction industry. To overcome these challenges, Vietnam is focusing on developing new, recycled, and smart construction materials. With the increasing rate of urbanization, the demand for construction materials is rising, while traditional materials extracted from natural mineral sources are becoming limited. This situation underscores the urgency of advancing sustainable building practices and the use of recycled materials [15]. In conclusion, while the adoption of recyclates in Vietnam's construction sector is still in its early stages, ongoing research and policy initiatives indicate a growing commitment to sustainable construction practices. Continued efforts in developing standards, raising awareness, and promoting innovative recycling processes are essential to fully realize the potential of recycled materials in the industry.

4 Recycling of building materials in Germany, Creation-Preparation-Recycling

In an era where sustainability is paramount, the construction industry is increasingly turning to innovative methods of material reuse and recycling. This chapter of recycled construction materials, focusing on three primary categories: reclaimed asphalt, crushed concrete, and masonry rubble and some additional materials. Each of these materials presents unique opportunities for repurposing, significantly contributing to resource conservation and environmental protection.

4.1 Finishing asphalt

Reclaimed asphalt is the collective term for asphalt recovered from roads and traffic areas that has not undergone any further processing. The reclaimed asphalt can be reactivated by heating and is usually placed again mixed with fresh mix. Mainly reuse takes place in road construction, alternative possibilities such as, civil engineering and pipeline construction or dam and dike construction, are mentioned in "Reuse and recycling of reclaimed asphalt guide, status 2020; Saxony State Office for the Environment, Agriculture and Geology".

4.2 Concrete quarry

The constituents of concrete are fine and coarse aggregates, possibly fine particulate additives, and cement. The concrete recovered from roads and structures is referred to as crushed concrete. Predominantly, crushed concrete is used to produce aggregate mixtures that are used as base courses in road construction. Fractionated aggregates can also be used in the production of concrete with recycled aggregates. See also the chapter "Recdemo - Complete utilization of the sand fraction from construction material recycling".

4.3 Masonry fracture

The collective term for the material produced during the demolition and reconstruction of masonry structures is masonry rubble. This material includes bricks, concrete and lightweight concrete, sand-lime bricks, aerated concrete as well as mortar and plaster. Recycled building materials made from masonry rubble are usually mixtures. The exception to this rule is broken bricks, which may be produced by demolition work in their pure form. Separate recycling of other masonry quarry components requires selective demolition and sorting.

Pure masonry rubble:
Brick aggregates
Find application in sports field construction and vegetation technology,
Component of base layers,
Component of aggregates for concrete production,
Production of masonry bricks (e. g. Buhl storage bricks).

Sand-lime brick grains:
Application in vegetation technology,
Component of base layers,
Raw material components for sand lime brick production,
Production of masonry stone from limestone quarry.

Aerated concrete recyclate:
Due to low strength of aerated concrete aggregates, use in road or concrete construction is excluded. The material can be used as an oil and chemical binder or as a water reservoir in roof substrates.

Lightweight concrete recyclates:
Use as aggregate for new lightweight concrete.

Use masonry rubble as a mixture:
It is mainly used for backfilling quarries and open pits. Masonry rubble that has undergone processing and is as free of foreign matter as possible can be used for paving construction roads or in road construction in agriculture and forestry.

4.4 Mineral construction waste

Mineral construction waste:
Plaster
Due to its recyclability, gypsum can be used directly for the production of new gypsum products. The prerequisite for this is waste with a high gypsum content without contamination by hazardous substances.

Fiber Cement
Fiber cement consists of cement and nowadays uses pulp and synthetic fibers. It is possible for unmixed fiber cement waste to be used in the production of cement clinker. During the burning process, the fibrous materials burn and the cement stone that remains is incorporated into the cement clinker.

Mineral wool
For the production of glass wool, the raw materials quartz sand, soda ash and limestone are used and between 50 and 70 % waste glass is added. For the production of stone wool, volcanic rocks such as diabase or basalt are used together with limestone and/or dolomite. Due to the health hazards posed by mineral wool, older products require special monitoring, which results in the strictest safety measures for renovation and maintenance measures, including landfilling. Remnants, offcuts and deconstruction material from "new" mineral wool can be returned to the manufacturing process.

4.5 Glass

Glass is a non-crystalline, inorganic material. In its simplest form, glass is made of quartz sand, alkali and alkaline earth oxides such as soda ash, limestone and dolomite, as well as its own and foreign cullet. Waste glass can be reused depending on its quality: Highest quality like screen glass, lighting glass, flat glass, high quality like container glass (Sensitive to off-color) and low quality like glass wool, foam glass or expanded glass (used in construction as insulation material).

5 Conservation of natural resources through material cycles in the construction industry

In its brochure "Conservation of natural resources through material cycles in the construction industry", KNBau sets out how material cycles in the construction industry can be better realized today and in the future. It identifies two fields of action: the recovery of secondary raw materials from existing buildings and the planning of buildings that conserve resources and can be recycled in the future. Among other things, it recommends to the public sector how high recycling rates for construction and demolition waste can still be achieved in the future through better promotion of innovative techniques or acceptance among those working in the construction industry, including through further training programs [16].

6 Current approaches to the implementation of the UN Sustainable Development Goals (SDGs) First steps to urban mining

Today, about half of the world's population lives in urban agglomerations. As the requirements for living comfort and quality are constantly changing, many buildings no longer meet the desired requirements and are therefore demolished or deconstructed. Consequently, large cities can be described as permanently running construction sites. The primary aim of selective building demolition is to recover the demolition materials by type so that they can be specifically processed into quality-assured secondary raw materials. In the work of A. Mettke, several examples of reuse and re-purposing are given. Separation and recycling examples are given for the following building materials: Construction waste, Road construction, Gypsum based construction wasteSoil and stones, Construction site waste (wood, glass, plastics, metals, insulation materials, floor coverings, etc.) [17].

7 Recdemo - Complete utilization of the sand fraction from the recycling of building materials

The Project in the EU LIFE program, LIFE00 ENV/D/000319 “RECDEMO” was selected as one of the top 25 projects in the LIFE Demonstration Program in the Assessment period 2004/2005 awarded. The aim of the project was to process the concrete crushed sand fraction from construction waste by means of a wet process to a suitable aggregate for concrete production as well as the complete demonstrate the recycling of the residual materials produced by this process. The result was that the quality of natural stone grains has been (e. g. due to grain damage due to the fracture of the old concrete and remaining cement adhesions) nevertheless not achieved. The concrete tests in particular (with proportions of up to 50 % crushed concrete sand in the total aggregate) have shown, however, that it would nevertheless be very possible to produce larger quantities of recycled processed concrete crushing sand in the production of concrete. The residual materials resulting from the wet processing of the concrete crushed sand, namely the fractions. Lightweight material and the finest fraction can, provided that the pollutant contents are demonstrably below the specified limits, as an addition to the digestion in the composting be used.

8 Secondary materials from building construction

Energy and material flows along the production and place of use of secondary materials from building construction for the building sector. The report [19] is the result of an exploratory study devoted in particular to the aspect of energy expenditures in the course of recycling in the construction sector. In this report, the recycling process of concrete, brick, sand-lime brick, gypsum, flat glass and mineral insulating materials is also described as already above. Additionally, building products made of PVC and petroleum-based insulation materials are considered. The focus of the report is mainly on the energy evaluation of the recycling process. For PVC profiles called recycled building materials the production of a PVC regranulate can be used to manufacture new PVC products, such as window frames and sewage pipes. For PVC flooring called recycled building materials renewed production of PVC flooring from finely ground old PVC flooring and unreinforced homogeneous PVC roofing membranes / waterproofing membranes for flat roof applications are possible. For petroleum-based insulation materials like PU materials, the only possible disposal method is controlled incineration in waste incineration plants, because this is the only way to ensure that any CFCs or HCFCs that may be present, which were previously used as a blowing gas, are destroyed harmlessly or do not enter the atmosphere. The recycling of old XPS and EPS insulation boards is primarily hindered by their HBCD contamination at least of EPS before 2015. In principle, the technical recycling of expanded polystyrene rigid foam (EPS) and extruded polystyrene insulation (XPS) is already fully developed. Recycled EPS, which consists mainly of packaging material or unmixed, uncontaminated offcuts, is shredded into small fractions and formed into new EPS products under steam. For construction timber a recycling in particleboard production is possible [19].

9 Current examples of recycled building materials

9.1 Concrete / Cement

Waste concrete, the main component of construction waste, can be efficiently recycled and is mainly used as road surfacing or backfill material. However, since no further resource recycling is expected for waste concrete, more efficient and productive recycling systems are being sought. This involves the production of inorganic building materials such as recycled cement from waste concrete powder. Studies show that blocks with desired strengths can be produced by adjusting the degree of consolidation and curing conditions. Based on these results, this study proposes a recycling system for concrete waste to reduce the amount of construction waste and prevent the depletion of resources [20]. At the Magnel Laboratory for Concrete Research in Belgium, a fully recyclable concrete was developed to achieve a closed concrete-cement-concrete material cycle [21]. As part of further research on this CRC, the environmental benefits were quantified and a life cycle assessment (LCA) was performed, the results of which were presented in [22]. It is shown that CRC could significantly reduce the global warming potential of concrete.

9.2 Polypropylene recycling from carpet waste

A team of researchers, including Fraunhofer IBP, has developed a novel recycling process in the EU project "ISOPREP". With this, polypropylene can be recovered from carpet waste for the first time. The recovered polypropylene approaches the quality of newly produced polypropylene. It is therefore also suitable for high-value products [23].

9.3 Waste tires

The Chemnitz Institute for Lightweight Structures is researching the ecological recycling of elastomers from old tires. Until now, scrap tires have mostly been shredded into relatively coarse granules and pressed with binders to make floor and fall protection mats or rubber coatings in automotive construction. But they have also been used as artificial turf granules for sports fields and playgrounds. New materials with high quality and performance are now being developed at the TU Chemnitz. For this purpose, very fine rubber flours are mixed with thermoplastic polymers. These so-called "thermoplastic-elastomer compounds" are meltable and can be processed into complex components, for example, by injection molding [24]. The book "Designing Building Products Made With Recycled Tires" of C. Hammer [25] is a guide which is intended to help developers manufacture and develop products from scrap tires for landscaping, road building, and construction. The document provides information on physical and technical properties of the raw material (rubber) as well as a listing of products that use scrap tires for manufacturing and energy and environmental impact of recycled end-of-life tires applied in building envelopes. In this study, the use of used tires in the building envelope was investigated. The tires are used shredded as insulation and as whole tires filled with soil. The main advantage of this application compared to conventional materials is the savings in gray energy [26].

9.4 Construction and insulation materials from waste paper

Wadding-like cellulose flakes are produced from waste paper by a mechanical shredding process. The insulation material is thus a recycled product. Salts are added as fire and rot protection. At companies such as isofloc or Isocell, the cellulose insulation material is made from shredded newspaper. The insulation is usually inserted into a structure using the blow-in or blow-up method [27]. A study conducted by the Higher Federal School of Agriculture Origin, investigated the recycling of old cellulose insulation as a drilling fertilizer. The results show that a biochar produced from cellulose insulation containing boron is suitable as a plant fertilizer and thus a closed cycle of the raw material can be produced [28].The company Richlite, produces materials from a composition of 65 % FSC certified or recycled paper and 35 % phenolic resin [29]. At the Technical University of Dresden, a cellulose water lightweight concrete (CFLC) was investigated, which is a cement-bound lightweight concrete based on cellulose fibers extracted from secondary fiber materials [30].

9.5 Waste wood recycling

One reason for the low recycling rate of waste wood in Germany can be found in the Waste Wood Ordinance, which is unique in Europe. It stipulates that material coated with halogen-organic compounds or wood treated with wood preservatives may not be used or may only be used to a very limited extent. Under [31], procedures for the sorting and recycling of waste wood are described. Sorted and hazardous-free waste wood, is mainly used in the production of particleboard and medium density fiberboard. The reprocessing of MDF panels was investigated under [32].

9.6 Sawdust

Lightweight wood concrete is concrete with admixture of wood chips which can come from residual materials of the wood industry. The idea of using wood chips and cement to produce a wood-chip concrete originated as early as 1930. Due to ecological and sustainability aspects, the potential of this material can be reconsidered. Due to its heat-insulating acoustic and fire-retardant properties, lightweight wood concrete is preferred in the field of sound and fire protection. The material can be used, for example, in block form, so-called wood-chip concrete mantle blocks as load-bearing and non-load-bearing interior and exterior walls. Disadvantage: From an economic point of view, lightweight wood concrete is usually the more expensive option. Advantage: Ecologically, the natural substances show advantages over other building materials. In addition, the main component, wood, is obtained from secondary raw materials from waste wood or wood residues. From a building physics point of view, lightweight wood concrete is very versatile [33]. Insulation material from sawdust is a fully biological insulation material made of wood chips, which can be used as insulation in wooden structures. Whey and soda are used for fire protection and as impregnation against fungal spores [34].

9.7 Straw use

Straw is a by-product of agriculture and has always been used as a building material. Currently, buildings in which straw is used as a building material are divided into non-load-bearing and load-bearing systems. In load-bearing construction, compressed straw bales are used as load-bearing elements and placed on top of each other like masonry blocks. As an auxiliary construction, wooden supports are placed at the corners so that the walls can be precisely aligned. In non-load-bearing systems, the straw is used only as insulation. Here, the straw is placed either in bale form or also as blown-in insulation in a load-bearing wooden structure [35]. The building materials manufacturer Maxit is presenting an ETIC system made of straw insulation boards, which is currently in the pilot phase, at "BAU 2019". Like conventional systems, the system can be applied to the exterior wall as insulation and plastered [36]. The material straw is often used in combination with clay. An example of this is the straw-light clay tamping technique, in which straw and clay are mixed and then placed in layers between formwork and compacted by tamping [37]. In [38], building boards made of rice husks are investigated for their thermal, acoustic and ecological characterization and compared with other innovative waste materials.

9.8 Textile

The Lucerne University of Applied Sciences and Arts is researching the recycling of discarded old clothes. Among other things, the first prototypes of insulating materials were presented which can be used for sound insulation as well as for thermal insulation [39]. A study was presented in the Journal of Building Engineering in which used bedspreads made of polyester and duck feathers are processed into thermal insulation [40].

9.9 Glass

Glass is a common material made from natural resources such as sand. Although much of the waste glass is recycled to make new glass products, a large portion still ends up in landfills. In [41], the use of waste glass in cement-based materials is studied. It was found that waste glass is unsuitable as a raw material substitute for the production of clinker and as a coarse aggregate due to its liquid state in the kiln and its smooth surface, respectively. Promising results were found in the incorporation of fine glass particles into cement-based materials due to the favorable pozzolanic reaction, which favors the mechanical properties. It was found that 20 % of the cement can be replaced by waste glass of 20 µm without adverse effects on the mechanical properties. At the University of Trieste, an innovative powder foaming process has been developed that is capable of producing thermally and acoustically insulating foams obtained by sol-gel and a subsequent freeze-drying process. The starting material for the foam is recycled glass which is ground into powder for the manufacturing process [42]. In another paper [43], the novel insulation material is compared and evaluated with conventional materials by means of a life cycle analysis. For some years now, various manufacturers have been offering foam glass insulation in the form of fills and slabbed tubes. The manufacturer Foamglas states that it uses up to 60 % recycled glass to produce the insulation material [45].

10 Current research projects Fraunhofer IBP

10.1 Processing masonry rubble

To recycle these huge quantities of mineral residues, Fraunhofer IBP is constantly developing new recycling technologies. In recent years, the focus of work was on processing concrete rubble - high time to start concentrating on masonry rubble! Most of today's masonry rubble, i. e. brick fragments with firmly adhering mortar and plaster residues, is mechanically crushed on a large scale and passed on in sub-loops - this is referred to as downcycling. In a work package, Fraunhofer IBP has now succeeded in extracting sorted secondary raw materials from masonry waste, thus demonstrating a genuine recycling process. How can masonry rubble be fully recycled? The pre-crushed masonry rubble is first processed by electrodynamic fragmentation (EDF). Under water, ultra-short lightning pulses are repeatedly discharged through the material to separate it - preferably along existing grain and phase boundaries. This removes any adhering mortar and plaster residues from the brick fragments. What is more, the process needs less energy than conventional treatment methods. The electrodynamic fragmentation results in a mixture of brick and mortar fragments, most of which are in the millimeter to centimeter range. In a second automated step, these fragments are then sorted into their respective materials for reuse in building products. Each particle larger than two millimeters in size is analyzed optically and spectroscopically in real time on a conveyor belt. Consequently, not only can rust-brown brick rubble be separated from gray mortar rubble, but particles particularly rich in gypsum can also be separated. How can the recycled material be utilized? The cleanly-sorted brick material obtained is suitable as a secondary raw material so can be used directly to produce new bricks. The mortar fraction can also be recycled by recovering the gypsum it contains with the ENSUBA process (see Fraunhofer IBP Annual Report 2017). The remaining mineral residues can then be used as a cement additive in the cement industry. Thus, in future, around 700 kilos of cleanly-sorted brick material could be extracted from one ton of masonry rubble to make new bricks and serve as a sustainable source of raw materials for the gypsum and cement industries. To further develop this and comparable processing methods accordingly, in a next step universal test beds for electrodynamic fragmentation and automatic processing masonry rubble - Fraunhofer IBP sorting will be installed as soon as possible: in Fraunhofer IBP's purpose-built research building for recycling building materials. The results of this and other development work by Fraunhofer IBP will help pave new paths to a sustainable future for our society, © Fraunhofer IBP [45].

Figure 1 Photos of masonry rubble by [45] fragments with firmly adhering mortar residues, right, masonry rubble is mostly made up of brick, left: via an automated sorting process, brick and mortar rubble can be separated from each other.

10.2 Separating ash and slag to manufacture resource-efficient building products

When it comes to resource-efficient recycling, the aim is to recover equivalent or better-quality base materials from the residues. The construction industry has a high demand for raw materials. At the same time, it produces large quantities of mineral waste in the form of leftover building materials, meaning that there is still potential for development in this regard. The use of construction waste, slag, dust and ash as sources of raw materials can make a significant contribution to conserving natural resources and ensuring the continued supply of mineral-based raw materials. The German Federal Ministry of Education and Research (BMBF) has recognized this potential and wants to further advance closed-loop recycling in Germany. The BAUSEP project is also being funded as part of the measure "Resource-efficient circular economy - Building and mineral cycles (ReMin)". The aim of this project is to recover secondary mineral raw materials from waste incineration ash and slag produced by the iron and steel industry and to use them to manufacture resource-efficient building products. Project goals: In a first step, appropriate investigations in both the technical and legal fields need to be carried out to assess the potential of using processed secondary raw materials recovered from waste incineration ash and slag to make building products. Methods will initially be developed in the laboratory and then implemented in an industrial environment. The focus in BAUSEP is on paving stones and drainage segments. In addition to their manufacture, the durability of these building products will also be evaluated. In order to establish a sustainable resource-efficient material cycle, the ability to recycle the manufactured products will then be assessed. To measure the sustainability of the new building products, all processes implemented in the project will be subjected to a life cycle assessment combined with a techno-economic analysis [45]. In the BAUSEP project, research is being conducted into how ash and slag can be separated so that it can be used to manufacture resource-efficient building products.

Project duration and funding

- Project time frame: February 2021 - January 2024

- Funded by the Federal Ministry of Education and Research (BMBF)

Figure 2 Shutterstock / PhotoChur

10.3 Aerated concrete with unusual properties: Amorphous Silica instead of sand

Autoclaved aerated concrete is comparatively light because it is highly porous, yet it offers very good thermal insulation. However, its production requires a lot of energy - after all, high temperatures of 180 to 200 degrees Celsius and pressures of between 12 and 13 bar are needed. The high energy consumption is associated with high CO_2 emissions. During production - an autoclaving process - complex mineral transformations take place. These lead to the formation of tobermorite and other calcium silicate hydrate phases. Tobermorite is the most important of these phases in aerated concrete: this is because it improves compressive strength and reduces shrinkage. The rate at which tobermorite forms depends on the process of dissolving silica (SiO_2 – n H_2O). Currently, it is common to use sand as a source of SiO_2 for the reduction of aerated concrete, but sand has a relatively low solubility in water. Amorphous silica, on the other hand, dissolves much better - this is well known. Silica instead of sand: How can the autoclaving temperature be optimized by replacing sand with silica? The idea: In this way, one could accelerate tobermorite synthesis and thus shorten the autoclaving time. In addition, it was investigated how replacing sand with amorphous silica affects the mechanical and microstructural properties of aerated concrete - depending on temperature and manufacturing time. The resulting mineralogical phases were characterized by means of quantitative and qualitative X-ray diffraction (XRD) and the mechanical properties of the aerated concretes were determined. The study led - depending on temperature and formulation - to a whole range of surprising results: Aerated concretes with a lower density and thus also improved thermal insulation properties. Aerated concretes with higher compressive strength - for masonry and slabs. Aerated concretes with fewer binders (cement and lime) in the formulations. Less energy consumption during the autoclaving process. Conservation of the resource "sand reduction of CO_2 emissions. Industrial waste containing SiO_2 can be used as a secondary raw material for aerated concrete production. The results of the study led to a

European patent application: EP 20 171 792.3, "Process for producing autoclaved aerated concrete using silica raw materials having higher solubility than quartz".

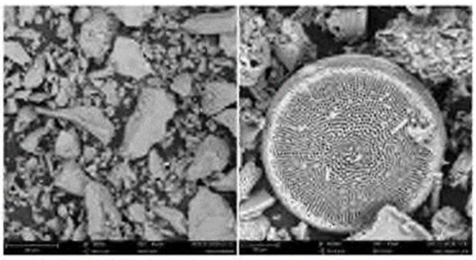

Figure 3 SEM images of amorphous silica and diatomaceous earth. Diatomaceous earth is the term used to describe the sediments (deposits) of diatoms. Their spherical skeletons consist of silicates and can be used in the construction sector, photos by Fraunhofer IBP.

11 Labels

11.1 Cradel to Cradel

Cradel to Cradel is an approach to a continuous and consistent circular economy. The registered association, which was founded in 2012, evaluates products according to the following criteria: Material health, circulatory capability, (Deployment) renewables, responsible use of water and social justice.

11.2 SCS Global Services

A global leader in third-party certification, auditing and standards development in the areas of environment, sustainability, food safety and quality since 1984. Among other things, SCS certifications will identify products with recycled content. The recycled content certificate is awarded, for example, for carpets, textiles, building products, wood and paper products, insulation materials, clothing, jewelry and more.

11.3 Singapore Green Label

The Singapore Green Labeling Scheme (SGLS) aims to help the public identify environmentally friendly products that meet certain eco-standards set by the scheme, and seeks to promote the level of eco-consumption in Singapore as well as identify the growing demand for greener products in the market. The scheme hopes to encourage manufacturers to develop and produce environmentally friendly products.

11.4 Thai Green Label

The Green Label is an environmental certification awarded to certain products that have been shown to have minimal harmful effects on the environment compared to other products that perform the same function. The Thai Green Label Scheme applies to products and services, but not to food, beverages and pharmaceuticals. The Thai Green Label Scheme was initiated by the Thailand Business Council for Sustainable Development (TBCSD) and formally launched in August 1994 by the Thailand Environment Institute (TEI) in cooperation with the Ministry of Industry. See [47] for a list of other labels related to environmental protection and recycling.

12 Planning/ Life cycle/ Energy

12.1 Improving the Recycling Potential of Buildings through Material Passports (MP): An Austrian Case Study.

A large proportion of building materials become waste at the end of a building's life cycle. For sustainability reasons, it is important to preserve or recycle urban stock and thus minimize the use of primary resources, which is why a material passport (MP) is an important tool. A MP serves as a tool for design optimization as well as an inventory of all materials used in a building, indicating the recycling potential and environmental impact of buildings. In this paper, the proof of concept for a MP is demonstrated on a use case, a residential building, evaluating a wood construction variant and a concrete construction variant [48].

12.2 New Life of the Building Materials- Recycle, Reuse and Recovery

This paper proposes to use "energy savings potential" to quantify the amount of energy in the end-of-life (EOL) phase that can be made usable in a new building. Recycling was found to have the highest energy savings potential of 53 %, while the energy savings potential of reuse was 6.2 % and that of incineration was only 0.4 %. A recycling strategy should be implemented for building elements with high concrete content (e. g. multi-story residential buildings). For building elements with high aluminum content (e. g. windows), reuse should be chosen instead of recycling [49]. The approach of reuse is particularly interesting here, especially for components such as windows and doors, the potential for energy savings through reuse is higher than through recycling .

12.3 Recycled value of building materials in building rating systems.

The selection of green building materials and products is by far the most controversial task in sustainable building. Determining the merits of building materials and products in terms of their recycled value, which seems to be a simple matter, is a very controversial issue in building rating systems. This paper proposes a method to evaluate energy savings from recycling of building materials, which can be a potential indicator of recycled value. The method considers material selection, construction and deconstruction technologies, and recycling frequency. The result of this study can be used in assessment tools as a separate factor from gray energy. Since grey energy affects potential recycling energy, another factor is defined based on these two factors to allow proper comparison and selection of materials based on their grey energy and recycling potential [50].

12.4 Exploring environmental benefits of reuse and recycle practices: A circular economy case study of a modular building

This study examines the environmental benefits of reuse practices compared to the circular economy. To test this, the environmental benefits of a prototype and a modular building specifically designed for disassembly and reuse were evaluated through a life cycle assessment of its components. The results of the LCA were then compared with the results of a contemporary design approach focused on the recyclability of materials. The results show that designing and building for reusable components reduces greenhouse gas emissions by 88 % compared to recycling, while benefiting several other environmental indicators tested [51].

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13 M5.1 Research proposal of wall building materials and insulating materials with recycled materials for Vietnam

In WP5, proposals are made for possible recycling solutions and implementations in Vietnam specifically for wall building materials and insulation materials. To suggest products for walls made of recycled materials different aspects have to be considered. The amount of available recycled materials is important, at the moment and in the near future. Also ideas for research work can be given. The price of the raw and the final building materials is of course important and also if the process how to make the products out of the raw materials shall be well known and the production facilities available. The following points has been discussed between the projects partners:

- EPS concrete (Huce), see A.1
- Cellular glass loose fill as load bearing insulation material (VIBM and IBP), A.2
- Foam glass gravel concrete or Cellular glass loose fill (VIBM and IBP), A.3
- VIBM concrete panels with 100 % fly ash (VIBM), A.4
- TDTU Cellulose insulation made of waste paper as insulation material (TDTU), [53]

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A.1 Lightweight concrete recycling EPS

Lightweight concrete recycling EPS

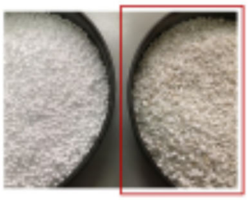
Raw material, production and composition

Raw material: Expanded polystyrene (EPS) waste, cement, sand, water, admixtures
Production: cleaning, milling, mixing, precast or in situ

The production technique is well known and production lines could be bought in Europe.

Form of delivery and field of application

Lightweight concrete recycling EPS is delivered as slabs (precast) for the walls, floors, lintels, etc., or can be used as a filling material (in situ).



Usage in Vietnam

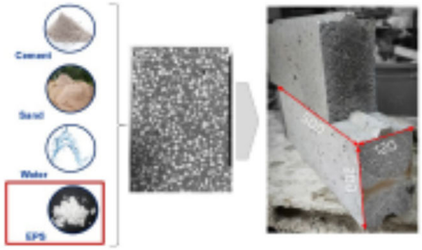
Recycling EPS in producing LWC in Vietnam construction has some advantages such as increased thermal, sound insulation properties, fireproof, and long service life. A disadvantage is very prone to segregation and has low compressive strength. A big advantage is that EPS LWC can be used to produce precast lightweight walls, floors, lintels, etc. to replace the traditional clay-fired brick masonry.

Building physics properties and aspects

Manufactured from recycled EPS
Lightweight
Resistant to water
Fireproof
Long service life
Easy and cheap placement
Used as thermal and sound insulation

Manufacturer (in Vietnam)

Nucewall: https://nucewall.vn/
DuraLight: https://duralight.web3b.com/
N-EPS: https://betongnhehcm.com/



Properties of EPS LWC

Thermal conductivity	0,30-0,40 W/(mK)
Density	900-1200 kg/m³
Compressive strength	3.0-10.0 MPa
Sound insulation	45 dB
Capillary Water Absorption ASTM C1585	0.80-1.00 kg/m²
Flamability	60 min.

Properties of EPS LWC slabs with density of 900 kg/m³

Size	2000×500×(70 & 100) mm
Weight	(63 & 90)±5 kg
Density	900±50 kg/m³
Compressive strength	≥ 3.0 MPa
Sound insulation	≥ (35 & 45) dB
Flamability	≥ (60 & 90) min.

Properties of EPS LWC slabs with density of 1200 kg/m³

Size	2000×500×(70 & 100) mm
Weight	(84 & 120)±5 kg
Density	900±50 kg/m³
Compressive strength	≥ 10.0 MPa
Flamability	≥ (60 & 90) min.

A.2 Datasheet of cellular glass loose fill as load bearing insulation material

Cellular glass loose fill

Raw material, production and composition
Raw material: glass waste
Production: cleaning, milling, mixing with additives and backing in the furnace at about 700°C, cooling down and cracking to gravel


The production technique is well known and production lines could be bought in Europe.

Producer of production lines:
SGS https://sgg-consulting.com/en/
BiFoam Franz Rottner Schaumglas GmbH https://www.bi-foam.de/
Geocell https://www.geocell-schaumglas.eu/

Form of delivery and field of application
Foam glass gravel is delivered as loose fill and can be used as load bearing insulation, as filling material for parking decks and flat roofs and for many other applications.

Usage in Vietnam
One advantage to use foam glass gravel in Vietnam is that it is high resistant to water, to fire, high pressure resistant and glass waste exists. For the production glass waste can be used which is not usable for producing new glass. A disadvantage is that it need energy to heat up the raw glass powder up to 700°C and not all type of glass should be taken because some glasses could be contaminated with copper or lead. A big advantage is that the technique for production is well known and the production line could be bought. Also there exist standards to handle the quality management and requirements needed for different applications. The foam glass gravel can be used also as material for foam glass concrete and save a lot of sand.

Manufacturer (in Europe)
Misapor AG https://www.misapor.ch/en/
Technopor https://www.technopor.com/
Veriso GmbH https://www.veriso.de/index.html
Ecoglas Steinbach Schaumglas GmbH https://www.ecoglas.de/
Geocell https://www.geocell-schaumglas.eu/
BiFoam Franz Rottner Schaumglas GmbH https://www.bi-foam.de/
Glapor Werk Mitterteich GmbH https://www.glapor.de/en/
Foamglas https://www.foamglas.com/en-gb

Building physics properties and aspects
Manufactured from recycled glass
High pressure resistance
Resistant to water
Fireproof
Long service life
Easy and cheap placement
Used as load bearing insulation and ….
Many other applications.

Thermal conductivity [W/mK]	0,080 w/(mK)
Loose bulk density [kg/³]	120 – 220 kg/m³
Installation specific density 1.3:1	156 – 260 kg/m³
Copressive stress at 10% deformation	≥ 660 kPa
Fire behaviour EN 13501-1	A1

Sources standards
EAD 040394-00-1201 Factory made cellular glass loose fill: https://www.eota.eu/eads

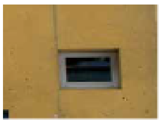
European Technical Approval ETA-13/0549 "Factory made cellular glass loose fill

A.3 Data sheet of foam glass concrete

Foam glass concrete

Raw material, production and composition

Raw material: foam glass gravel and concrete
Production: at the building site according to the advice of the manufacturer



There exist two production systems and two patents

Form of delivery and field of application

On the building site the foam glass loose fill and the cement mixture is delivered. The foam glass concrete is used for the walls auf houses and complete monolithic structures of houses including interior walls and roofs and sometimes even some furniture structure.

Usage in Vietnam

One advantage to use foam glass concrete in Vietnam is that the light weight concrete is high pressure resistant and at the same time it has a high thermal resistance. Beside that a high part of the recycling material foam glass loose fill is used. And this avoids sand. Because foam glass loose fill is at the moment not produced in Vietnam the first step would be to build up a production for that and in the second step the foam glass concrete can use it. Because foam glass loose fill has to be baked at a temperature of about 700°C the price of the foam glass concrete depends also on the price for energy in Vietnam.

Manufacturer (in Europe)

Misapor AG https://www.misapor.ch/en/
Technopor https://www.technopor.com/
https://www.technopor.com/produkt-daemmbeton/daemmbeton/monolithisch-bauen

Building physics properties and aspects

Light weight concrete with foam glass gravel
High pressure resistance
High thermal resistance
Avoid usage of sand.
Monolithic building system
High part of recycling material
High durability

Thermal conductivity	0,27 W/(mK)
Density	800 – 1000 kg/m³
Cube compressive strength	11 N/mm²
Modulus of elasticity	8 N/mm²
Diffusion resistance coefficient	μ = 20

https://www.technopor.com/produkt-daemmbeton/planung/technische-daten
https://www.misapor.ch/de/download-center/

A.4 Structural lightweight concrete using fly ash cenospheres (FAC)

Structural lightweight concrete using fly ash cenospheres (FAC)

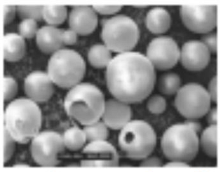
Raw material, production and composition

FAC, a coal combustion by-product at a thermal power plant, is a lightweight hollow sphere with a size of 30-300 µm that is made up largely of silica and alumina filled with air and gases.
Raw material: Fly ash cenosphere (FAC) waste, cement, sand, water, admixtures
Production: selecting, mixing, precast or in situ

The production technique is common and production lines could be bought in Europe.

Form of delivery and field of application

Structural lightweight concrete using FAC is delivered as slabs (precast) for the walls, floors, lintels, etc., or can be used as a filling material (in situ).



Usage in Vietnam

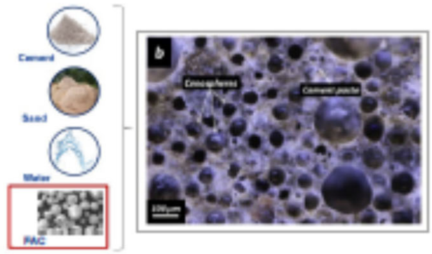
Recycling FAC in producing LWC in Vietnam construction has some advantages such as increased thermal, sound insulation properties, strength, energy saving and long service life. A disadvantage is very prone to segregation and high price. A big advantage is that EPS LWC can be used to produce precast structural lightweight walls, floors, lintels, etc. to replace the traditional concrete.

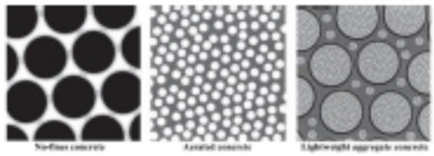
Building physics properties and aspects

Manufactured from recycled FAC
Lightweight
Thermal & Sound insulation
Long service life
High strength
Reduce building loads
Energy saving
Environmental protection

Manufacturer (in Vietnam): cenosphere

Song Da Cao Cuong: https://www.songdacaocuong.vn/
Song Thao: https://cenosphere-microsphere-vietnam.business.site/
CTA: https://vlxdcta.vn/bot-xi-cenosphere-sp480986.html





Properties of structural LWC using FAC

Flowability	15.0-20.0 cm
Density	1300-1600 kg/m³
Compressive strength	≥ 40.0 MPa
Flexural strength	≥ 7 MPa
Water absorption	4.0 – 6.0 %
Thermal conductivity	0,35-0,70 W/(mK)