the little book of Bio-Based Fibre Materials in Passivhaus Construction in Latin America

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imagination
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The Little Book of BIO-BASED FIBRE MATERIALS IN PASSIVHAUS Construction in Latin America

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Contents

What this Little Book tells you

This Little Book tells you about how buildings have a significant impact on climate change. The building industry in Latin America is shifting slowly towards a more resilient architecture; our planet needs a faster response. The time to act is NOW! Passivhaus design, construction and innovation offer a comprehensive range of solutions to mitigate climate change and positively impact the UN's Sustainable Development Goals (SDGs). Additionally, incorporating natural materials into Passivhaus buildings makes them more sustainable and healthier, with clear long-term advantages for occupants and the environment.

The change to make Latin American buildings more resilient and resource-efficient needs to start now! We all can help from our different positions by engaging and actively participate in the discussion of sustainable buildings. Local and National governments should commit to exploring and developing different strategies which incorporate mitigation actions in the building industry. Academics should research and give informed advice for policymaking. Industry innovation and development is vital to make available the process and materials needed for the change.

What is Passivhaus?

Passivhaus (Passive House) refers to a design method for ultra-low energy buildings that are extremely comfortable and economical to operate. Passivhaus evolved from Swedish super-insulated homes and passive solar energy to minimise space heating and the heat that escapes (leaks) from a building structure and through the different building elements (i.e., walls, doors, windows), also known as thermal transmittance or U-values [1]. In 1998, Professor Wolfgang Feist from the Institute for Housing and Environment in Germany and Professor Bo Adamson from Lund University in Sweden developed the Passivhaus method and built the first Passivhaus dwelling in Darmstadt, Germany in 1990. These developments led to the founding of the Passive House Institute in 1996, which continues today as the leading global centre of research and development to advance and adopt the Passivhaus performance standard. Over time, Passivhaus evolved from a method for cold climates to warmer or temperate climates where cooling is also of primary concern in addition to heating.

The Passive House Institute (PHI) defines Passivhaus as "[…] a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air [2]". The Passivhaus design has five (5) essential principles (Figure 1), including the following: (1) super-insulation, (2) thermal bridge free construction, (3) airtight building envelope, (4) adequate ventilation strategy and (5) high-performance doors and windows [3].

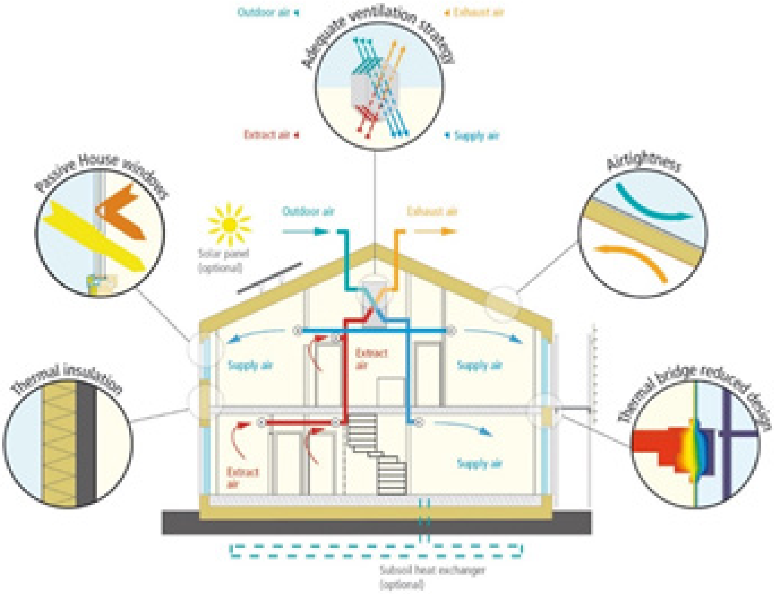


Figure 1. Passivhaus principles. Source: Passive House Institute [4].

Table 1 illustrates the main criteria requirements for Passivhaus certification. The performance standards are typically calculated utilising the Passive House Planning Package (PHPP) software that guides and support architects and building designers from the early stages of a project. The different levels for Passivhaus certification include: EnerPHit for refurbishment projects, Passivhaus Plus for nearly zero-energy buildings (nZEB), Passivhaus Premium for positive energy buildings and Passivhaus Classic for low-energy buildings.

In temperate and warm climates, such as those found throughout LATAM, the cooling load and demand are as crucial as the heating calculations to avoid the use of conventional cooling/heating systems to provide comfortable indoor environments. Passivhaus indoor temperatures (≤25°C) in homes are delivered through the supply-air heating/cooling loads that should not exceed 10 W/m^2. To deliver the desired thermal comfort levels, the mechanical ventilation system with energy recovery should supply 30 m^3/h/per person of fresh air, thereby linking energy-efficient design to high levels of thermal comfort and indoor air quality.

Table 1. Overview of the main criteria requirements for the Passivhaus certification.

Passivhaus Certification Criteria (Residential)	Cool-Moderate Climate (Central European)	
Specific heating demand	≤15	kWh/(m^{2}a)
OR specific heating load	≤10	W/m^2
Specific cooling demand	≤15	kWh/(m^{2}a) + 0.3 W/(m^{2}aK). DDH
OR specific cooling load	≤10	W/m^2
AND specific cooling demand	≤4	kWh/(m^{2}a). de + 2 • 0.3 W/(m^{2}aK). DDH-75 kWh/(m^{2}a)
Specific total primary energy demand	≤120	kWh/m^2/a
Airtightness n50	≤0.6	h-1 (@50 Pa)
Overheating frequency	10%	Percentage of time with operative temperature above 25 °C

de Annual mean external air temperature (°C). DDH refers to Dry Degree Hours.

The following section briefly describes the design concept for Passivhaus buildings. Additional detailed guidance is available in the Passive House Planning Package (PHPP) manual.

Passivhaus buildings have freedom in the *building form* design, but their orientation, shape and size must be planned carefully. The relationship between the surface area (A) of the building exterior – also known as the building envelope – and the building volume (V) indicated by the A/V ratio, changes as the building is modified. Hence, the A/V ratio is an essential factor for cooling and heating demand, regardless of the building envelope thermal transmittance value (U-value) [5]. As smaller buildings typically have higher A/V ratios (1.1–1.3 m^2/m^3), they also establish higher penalties than larger buildings with lower A/V ratios (0.46 m^2/m^3).

Passivhaus homes take advantage of *super-insulation* in external flooring, walls and ceiling to decrease the heat/cooling transfer between indoors and outdoors. Insulation is crucial when the difference between the desired indoor and outdoor temperature is high. However, in temperate climates, this can be less crucial [6] as these differences are typically lower. The typical U-values (0.10–0.15 W/m^{2}K) for Passivhaus walls [7] can be delivered using an extensive range of thermal insulation. Natural fibres from vegetal or animal origins are crucial elements for CO_2 emissions sequestration without compromising the indoor air quality. For instance, Passivhaus buildings have included mineral wool of thicknesses between 200 – 400 mm and 500 mm thick straw bale walls.

Passivhaus doors and windows influence thermal comfort as they reduce, or even eliminate, the risk of condensation, drafts and mould growth. The units are designed to maximise the solar gains to warm the building passively. The windows combine two or three glass layers and are usually filled with inert gas, such as argon or krypton. The window unit G-value refers to solar gain efficiency and gauges the solar heat transfer that infiltrates through a window section compared to the energy that reaches it. The higher the G-value, the higher the solar transmission. Typical U-values for Passivhaus windows are <0.8 W/m^{2}K and should be implemented thoughtfully. Window sizing is a crucial design element as smaller windows reduce heat loss and solar gains, reduce contact with the exterior and impact the opening size and ventilation. Passivhaus windows are traditionally limited to 0.8 W/m^{2}K [8]. However, this varies in warmer climates where the units can have higher U-values [9], [10] as the temperature difference between indoor and outdoor is diminished. Windows are vital to balance overheating in summer and heat gains in winter. Similar to windows, doors should be airtight and have a U-value of 0.8 W/m^{2}K.

Traditionally, ventilation in Passivhaus dwellings is achieved through *Mechanical Ventilation with Heat Recovery (MVHR)* systems to provide an uninterrupted supply of fresh air whilst optimising occupant comfort and reducing energy losses for heating/cooling by recovering heat from extracted air [11]. Nonetheless, ventilation can be achieved through other mechanical, natural or hybrid methods as long as they do not compromise the heating/cooling loads and demands and provide appropriate air flows. Passivhaus dwellings should deliver 0.3 air change rate per hour (ach/h) as a whole house minimum and guarantee a fresh air demand of 30 m^3/h per occupant and a minimum extract rate from wet rooms, kitchens and bathrooms of 60 m^3/h and 40 m^3/h, respectively.

Passivhaus buildings should adhere to high levels of *airtightness* to avoid thermal losses through air infiltration. Air barriers that seal construction joints and penetrations across the building envelope are essential to attaining the mandatory airtightness level [12]. These barriers are typically placed on the warm side of a building and protect the insulation and building structure from moisture. The wind barrier layer, typically placed outside the building fabric, protects the building envelope from cold air. Both layers are mandatory and must be considered from the early design stage. An on-site airtightness test or blower door test that measures total leakage through the building envelope is also required to verify airtightness conditions. Passivhaus buildings should carry under-pressure and over-pressure blower door test and achieve ≤ 0.6h−1 [11] in the n50 test—airtightness target defined by the number of air changes per hour at a reference of ±50 Pascals.

Thermal bridges are components of the building envelope that conduct energy, in the means of heat or cooling, between the interior and exterior of building structures. The thermal bridges can result in significant energy losses, internal condensation and dampness. The most common thermal bridge types are geometric, correlated to the building shape, and constructional when a construction material penetrates the insulation. Thermal bridges should be minimised by design, modelled and assessed via virtual simulation or replicated from reference detail sources for Passivhaus buildings such as those in the IBO Book [13], [14].

Finally, it is necessary to incorporate *energy-efficient technologies* for domestic hot water and electrical appliances to meet the final energy demand requirements. “It is a part of the Passive House philosophy that efficient technologies are also used to minimise the other sources of energy consumption in the building, notably electricity for household appliances [11].” Hot water connections for washing machines and dishwashers, LED bulbs, fluorescent lamps and airing cabinets are examples of practices that decrease energy consumption without compromising indoor environmental comfort levels [7], [11].

Passivhaus standard in Latin America

The Passivhaus Standard was first introduced to the LATAM context by Marcelo Huenchuñir in 2010. They designed a branch of the 'Banco BCI Vitacura' in Santiago de Chile to the Passivhaus Standard. Since then, a few other office buildings followed. 2014 saw the first Passivhaus certified residential building in Mexico City (Mexico), followed by another one in Farellones (Chile). These buildings showed that achieving the Passivhaus certification was viable in residential and office buildings. Since then, several studies have looked at the performance and potential for the Passivhaus Standard in LATAM [15], [16]. As Passivhaus dwellings proved to deliver the desired energy efficiency, further projects seek to demonstrate the added benefits of building with natural materials. In 2014, the first cross-laminated timber (CLT) Passivhaus dwelling was designed and built in Chile, proving the Passivhaus potential to reduce the carbon footprint in the construction and use of the building.

Passivhaus buildings have also set new standards on the building industry and training. Since 2013 when the first Passivhaus Designer training took place in Chile. Since then, the course adapted the LATAM context and building practices. In 2017, the Passivhaus Expert course was launched in Chile. These professional trainings are now offered in several LATAM countries and it is even possible to take them online. Alongside the training, the construction industry has developed solutions for Passivhaus construction, making it easier to design and build in LATAM.

The Passivhaus development in LATAM has the support from several Passivhaus professionals' networks around LATAM, such as the Chilean and Brazilian. In 2019 several of these networks, with the support of the Passivhaus Institute and internationally recognised Passivhaus professionals founded the Passivhaus Latin American Institute, also known as ILAPH. Up to January 2021, ILAPH's network has extended to 16 of the 19 LATAM countries (Figure 2) with a network of 35 Certified Passivhaus Designers and 15 Certified Passivhaus Tradespersons, in addition to numerous professionals not yet certified.

Figure 2. ILAPH's network in LATAM.

Passivhaus Standard and Sustainable Development Goals (SDGs)

The Sustainable Development Goals (SDGs) or Global Goals are "a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030" (UNDP, 2015). The 17 goals are made tangible through 169 targets and 303 indicators that attempt to focus attention on a 'means of implementation' to mitigate against a lack of tangible action that previous goals have been criticised for. Importantly, the SDGs aim to recognise the considerable link between social, economic and environmental outcomes. For example, they are ensuring that short-term improvements in wellbeing do not risk undermining long-term environmental consequences. The ability of design to engage real people and communities, understand everyday problems and implement the ‘right’ solution, not just the ‘newest technology’, enables it to act as a bridge between other disciplines. It is an important and growing voice in this field that helps to bridge the gap between the rapid advancements in science, technology and engineering with real people, challenges and contexts on an everyday level.

Ultra-energy-efficient construction, such as Passivhaus, has the potential for attaining significant positive contribution while minimising negative implications for implementing several SDGs. The goals of such implementation can be defined through a project contribution to specific targets and indicators. As such, Passivhaus design, construction and innovation have the capacity to positively impact the following SDGs:

Goal 03 Ensure healthy lives and promote wellbeing for all at all ages – Since heath and quality of housing are inextricably linked.

> *Target 3.9* By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
>
> > *Indicator 3.9.1* Mortality rate attributed to household and ambient air pollution.

Goal 07 Ensure access to affordable, reliable, sustainable and modern energy for all – Creating low-energy buildings and promoting the adoption of sustainable energy services.

> *Target 7.1* By 2030, ensure universal access to affordable, reliable and modern energy services.
>
> > *Indicator 7.1.2* Proportion of population with primary reliance on clean fuels and technology.

Goal 09 Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation—Industry, innovation and infrastructure associated with Passivhaus design, construction and maintenance.

> *Target 9.4* By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.

Indicator 9.4.1 CO_2 emission per unit of value added.

Goal 11 Make cities and human settlements inclusive, safe, resilient and sustainable – Improving the quality of housing and providing resilient buildings using local materials.

Target 11.1 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities.

Indicator 11.1.1 Proportion of urban population living in slums, informal settlements or inadequate housing.

Target 11.c Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilising local materials.

Indicator 11.c.1 Proportion of financial support to the least developed countries that is allocated to the construction and retrofitting of sustainable, resilient and resource-efficient buildings utilising local materials.

Goal 13 Take urgent action to combat climate change and its impacts – Reducing the energy consumption associated with the built environment.

Target 13.2 Integrate climate change measures into national policies, strategies and planning.

Indicator 13.2.1 Number of countries that have communicated the establishment or operationalisation of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other).

Bio-based materials in new and retrofitted buildings

While buildings provide a wide range of benefits to the community and humans, they also have an enormous impact on health and the environment. Buildings consume around 21% of the energy [17] and are responsible for almost 25% of the CO_2 emissions in Latin America [16]. Moreover, buildings consume a considerable amount of natural resources throughout their lifetime. Therefore, it is essential to thoughtfully consider using appropriate building materials in the early design phase to minimise the potential negative impact on the environment. Natural and local materials should be prioritised over other materials detrimental to the environment.

Natural materials for sustainable construction

Natural materials are a vital aspect of creating sustainable and healthier buildings, with clear long-term advantages for occupants and the environment. Natural building materials are materials that are abundant in a particular region and are rapidly renewable. Beyond the inherent energy and carbon savings, natural materials in construction increase the earthquake resilience, humidity regulation of the indoor environment and promote community involvement and education.

One of the most significant advantages of natural construction materials is that they have less embodied energy than traditional building materials resulting in fewer carbon emissions and energy required for manufacture and transport. Another important factor is the creation of overall healthy buildings. Natural materials can buffer the humidity, mitigate moisture, improve indoor air quality and allow the building to 'breath'. Natural materials can be classified into two primary groups including: (1) fibre and (2) earth materials.

Fibre materials

Fibre materials in construction tend to originate primarily from vegetable sources such as timber and straw. However, some animal fibres, including wool, are also used in construction, primarily in insulation materials. The diversity and flexibility of fibre materials deem them ideal for construction. They can be used in the structure, walls, ceiling and flooring depending on their particular properties. On some occasions, they can also be mixed with some natural clays or other earth materials such as hempcrete. The most common fibre materials in construction including the following:

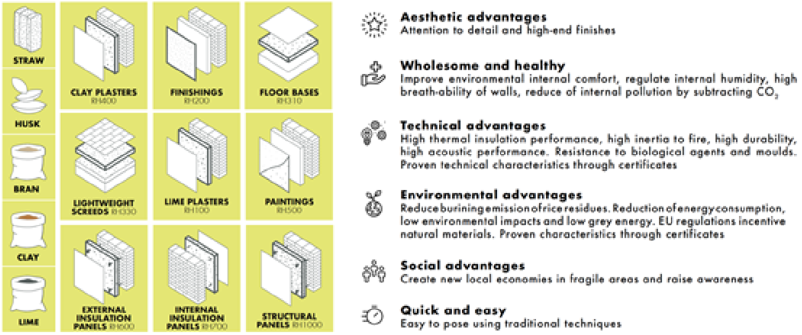
- *Timber* is a natural material with high carbon storage ability used in construction through different methods such as cross-laminated materials, glued laminated timber, structural composite lumber and wood I-joists. The use of timber can also reduce the transport associated with CO_2 emissions and also lead to the use of locally grown timber and investment in woodland creation and management.
- *Strawbale* construction is a building method that uses bales of straw (wheat, rice, rye) for the structure, building insulation or both. The advantages of this method are the nature of straw, cost, availability, naturally fire-retardant, high-insulation values and also carbon sequestration [18].
- *Bamboo* is a natural composite material with high strength-to-weight that can be used primarily as a structural element [19]. The advantages of this material lie primarily in its strength and the easy

way of harvesting.

- *Hempcrete* (hemp-lime) is a biocomposite material where hemp hurds are mixed with lime, sand or pozzolans and can be used for construction or insulation, although not as a structural material. This material is ideal for most climates as it provides both high levels of insulation and thermal mass.
- *Wool* is an animal fibre used for insulation that can be kept together through mechanical or polyester adhesives commonly used on timber frame constructions. As an insulation material, it has added value as acoustic and thermal insulation. Additionally, it is a natural, sustainable and recyclable material with a low embodied carbon emission.
- *Rice Husk* is a by-product of rice, the most consumed food crop in the world. A wide array of construction materials, including plasters, screeds, finishings, floor bases, exterior/interior insulation and structural panels, are derived from rice residues eliminating waste pollution and promoting circular economy from the field to the construction site.

Earth materials

Building with earth involves using unfired bricks or rammed earth. The unfired bricks are produced similarly to those fired—using earth and liquid binding mix, which is then compressed to shape the earth without heating



Aesthetic advantages
Attention to detail and high-end finishes

Wholesome and healthy
Improve environmental internal comfort, regulate internal humidity, high breath-ability of walls, reduce of internal pollution by subtracting CO_2

Technical advantages
High thermal insulation performance, high inertia to fire, high durability, high acoustic performance. Resistance to biological agents and moulds. Proven technical characteristics through certificates

Environmental advantages
Reduceburiningemissionofriceresidues. Reductionofenergyconsumption, low environmental impacts and low grey energy. EU regulations incentive natural materials. Proven characteristics through certificates

Social advantages
Create new local economies in fragile areas and raise awareness

Quick and easy
Easy to pose using traditional techniques

Figure 3. Rice husk panels. Source: www.ricehouse.it

the earth. Rammed earth construction usually involves compacting damp earth into layers inside a frame that is removed to let the earth dry.

Although the techniques vary depending on the climate, working with unfired earth and rammed earth produces a very low carbon footprint. These materials use minimal energy for extraction, transportation and work, mainly using local earth or clays. While earth and clay materials do not have the high insulation properties of natural fibres, they offer high thermal mass properties to buffer heat. This makes them an ideal material as an alternative to concrete or brick internal walls. Additionally, these materials can also be mixed with vegetable fibres or be incorporated as clay plasters to provide a natural finish for walls and ceilings.

The current state of natural materials in Latin America

The use of natural materials is growing rapidly throughout the LATAM region as bio-based aggregates penetrate the construction industry and the development of renewable products increases the use of environmentally friendly polymers. With rapid urbanisation, Latam countries have been scaling-up green building methods and, in some cases, achieve significant reductions in energy consumption, water use, CO_2 emissions and solid waste [20]. Countries including Brazil, Mexico, Colombia, Chile and Peru have implemented varying tax and finance incentives to accelerate sustainable regional construction. At 6 times the size of Europe and 2 times the rest of the world, the photosynthesis basin in the LATAM region provides a powerful natural environment for cultivating and harvesting bio-based materials.

Sustainable Building Materials and SDGs

Along with the SDGs associated with energy-efficient construction, including Passivhaus, building with sustainable and natural materials has the potential for attaining significant positive contribution while minimising negative implications for implementing several SDGs. The SDGs complement and support the application of those specific targets and indicators described as follows:

- *Goal 03* Ensure healthy lives and promote wellbeing for all at all age. Natural material properties allow for better control of the indoor environment promoting better indoor air quality, thermal comfort and healthier indoor environments.
- *Goal 09* Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation. Considering industry, innovation and infrastructure related to research, design, construction and maintenance associated with natural materials.
- *Goal 11* Make cities and human settlements inclusive, safe, resilient and sustainable. Generating and improving housing using sustainable and natural materials.
- *Goal 12* Ensure sustainable consumption and production patterns. The use of natural materials ensure that the building can be recycled, safety disposed or returned to the ground at the end of its life cycle.
- *Goal 13* Take urgent action to combat climate change and its impacts. Natural materials reduce the embodied energy and have the potential for CO_2 emission’s sequestration.

Case studies: Natural materials for Passivhaus construction

In order to fully realise all of the tangential benefits of sustainable construction, energy-efficient building design standards like Passivhaus will have substantial impact in the sector but must also include integration of bio-based building materials to address natural resources and overall carbon footprint for maximal positive SDG impact. Therefore, building design and construction that incorporate both low-energy and natural materials will inevitably experience rapid utilisation. This emerging trend has supported new technologies and development of materials based on renewable sources, such as the straw construction system created by EU-based EcoCocon.

Vegetal fibres and Passivhaus buildings

Strategies to minimise the environmental impact of construction should consider bio-based materials. In addition, other strategies to reduce carbon emissions focus on the improvement of insulation, building design, heating/cooling systems and use of renewable sources for energy [21]. These strategies are already addressed by the Passivhaus and some pioneer Passivhaus dwellings such as the Larixhaus have also implemented the use of vegetable fibres as main construction materials.

When one thinks of a house built with straw bale, the first thoughts that naturally come to mind are far from what new technologies and design innovation have produced. Modern straw bale homes have the same quality and aesthetics as conventional dwellings. However, straw bale has excellent additional attributes such as low embodied energy, great insulation performance, rapidly renewable cultivation, carbon-sinking and health benefits. Modern construction techniques and design innovation have incorporated timber and straw bale into Passivhaus homes. In fact, as of October 2020, the Passivhaus database recorded 15 Passivhaus projects built with straw bale [22] located in Australia (1), France (6), the Netherlands (1), New Zealand (1), Romania (1), Spain (3) and the UK (2).

Larixhaus

In 2013, Larixhaus, a two-story dwelling and the first straw bale Passivhaus certified dwelling, was built in Collsuspina, Spain. The two-bedroom house has approximately 92 m^2 of conditioned space and utilises a prefabricated wood and straw bale system to guarantee efficient building performance. Key features of the construction process include the use of natural materials (straw, timber and cork) that reduce the embodied energy and CO_2 footprint considerably versus traditionally constructed homes. The prefabrication of building components reduces on-site waste and results in a rapid on-site assembly and quality detailing. The timber structure and larch cladding are PEFC certified. Thermal insulation is provided by wheat straw sourced locally from the Costa Brava. Straw bales are large-format 1200mm x 700mm x 400mm, positioned vertically within the timber frame. The construction details of the Lariuxhaus are described in Table 2.

The use of non-toxic, natural and renewable construction materials and mechanical ventilation with heat recovery (MVHR) system guarantees high indoor air quality levels. The energy calculation in the design face estimated an annual heating demand of 12 kWh/(m^{2}a), which is 90% below Spain’s national average of 133 kWh/(m^{2}a) and a total primary energy requirement of 107 kWh/(m^{2}a). Between 2015 – 2017, the house performance was monitored and generated impressive results as follows: (A) annual heating demand of 2.73 kWh/(m^{2}a) and (B) total primary energy requirement of 81.90 kWh/(m^{2}a) [23]. This translates to an annual electricity bill of ~£495.00. Figure 4 details the layout of the Larixhaus and Figure 5 displays the timeline for the design and construction of the house, emphasising the straw bale installation process during the construction.

Table 2. Construction details of the Larixhaus building elements.

Building element	Exterior Wall	Floor slab	Roof
Layer 1 (inside/bottom)	12 mm gypsum fibreboard (Fermacell)	130 mm XPS insulation [034]	15 mm timber board (Fir)
Layer 2	35 mm service void between timber battens at 6%	350 mm reinforced concrete floor slab	22 mm OSB 4 [air-tight layer]
Layer 3	22 mm OSB 4 [air-tight layer]	80 mm Pavaflex wood fibre insulation [038] between timber joists at 10%	400 mm straw bale insulation [059] between timber joists at 9%
Layer 4	400 mm straw bale insulation [059] between timber joists at 8%	22 mm timber flooring	16 mm wood fibre breather board (DFP Kronolux)
Layer 5	16 mm wood fibre breather board (DFP Kronolux)	60 mm XPS insulation [034] round the edge of the floor slab	Timber battens and roof tiles
Layer 6 (Outside/top)	Wind tight membrane and ventilated larch rainscreen cladding, fixed on external timber battens		
U-value	0.146 W/(m^{2}K)	0.164 W/(m^{2}K)	0.147 W/(m^{2}K)

Figure 4. Ground and first floor layout of the Larixhaus. Source: [23]

Solutions and methods used in Passivhaus construction

The implementation of bio-based materials in Passivhaus construction could go further than just timber, as we saw in the last case study. The opportunities for innovation in Passivhaus construction are only limited by our ability to build with different materials. However, one of the biggest challenges is to achieve the desired thermal resistance in the building envelope. To address this issue, we have two options. The first one, perhaps the more traditional, follow approved construction details replicating them on site. The second is to build with prefabricated materials with the added benefits of being carefully designed and built to match each project. Therefore, ensuring that the bio-based materials are well protected against undesired effects of the outdoor environment. Such is the case of EcoCocon, our next case study as an innovative solution for building Passivhaus dwellings.

EcoCocon

EcoCocon is a 'Passivhaus component' certified prefabricated panel system made from natural renewable materials – timber, straw and clay. The panels are airtight yet breathable, allowing for internal humidity regulation. Additionally, each panel has a CO_2 sequestration potential of 97.6 kg/m^2 and a CO_2 emission during the production of 2.8 kg/m^2. Passivhaus certification properties of the construction system are described in Table 3 and illustrated in Figure 6.

Figure 5. Design and construction timeline Larixhaus. Adapted from: http://novadomushabitat.com/consultoria-larixhaus/

Table 3. Construction details of the EcoCocon panel. Source: https://ecococon.eu/assets/downloads/ph-certificate-ecococon-(en).pdf

	EcoCocon panel
Layer 1 (inside/bottom)	7 mm fine clay plaster
Layer 2	Reinforcing mesh
Layer 3	30 mm base clay coat
Layer 4	400 mm timer-straw panel with a 10%-90% ratio of timer-straw
Layer 5	Airtight membrane
Layer 6	60-100 mm wood fibreboard
Layer 7 (Outside/top)	Plaster or ventilated facade
U-value	0.131 W/(m2K) - 60 mm of wood fibreboard
	0.119 W/(m2K) - 100 mm of wood fibreboard
	0.109 W/(m2K) - 140 mm of wood fibreboard

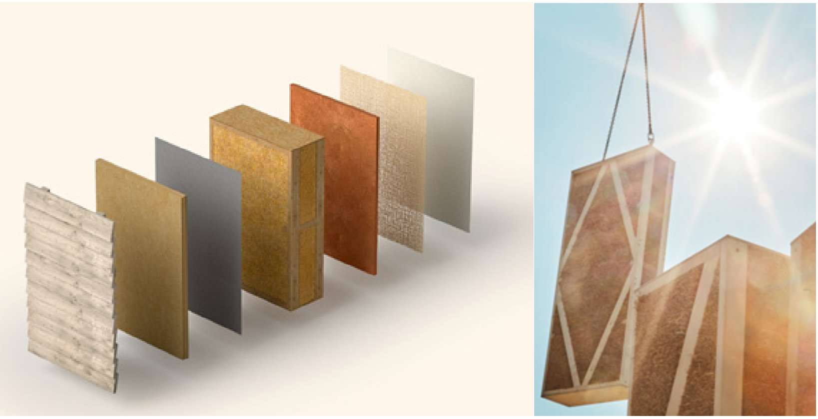


Figure 6 Detail of the panel and placement. Source: https://ecococon.eu/gb/

Since the EcoCocon panels are made in an offsite manufacturing facility rather than in situ, the product line benefits from industrialised construction's inherent sustainability and efficiencies. Additionally, they offer customised sizes with increments of 1 mm providing great flexibility with almost endless possibilities and adaption to different architectural typologies and designs. The panels include standard and braced panels, lintels, columns, sills and inclined gable wall elements that can meet different

Figure 7 Detail of the EcoCocon panel and placement. Source: https://ecococon.eu/gb/

structural demands depending on panel placement. Additional strength can be added with plywood reinforced elements. One of the most significant advantages of Passivhaus construction is that the system is designed to be load-bearing, thereby avoiding energy-inefficient thermal bridges.

Several Passivhaus buildings, including homes and gyms, have been built in over 20 countries such as the UK, Finland, Sweden, the Netherlands, Poland, Switzerland, Slovakia and the USA. Although the EcoCocon certification for Passivhaus construction was obtained for cold and temperate climates, it can also be used in warm climates, such as those in Latin America.

Fibre materials as Passivhaus construction materials in Latin America

Latin America is often referred to as the Photosynthesis Continent due to the climate conditions for plants to achieve rapid renewable growth.

A by-product of the accelerated natural growth in the region results in an enormous amount of agricultural waste and transformative opportunity for research and development (R&D) of building materials throughout LATAM. A widespread circular economy approach to product development would provide invaluable access to sustainable materials and result in a strong environmental impact and paradigm shift towards bio-based construction. The use of natural resources in building products will greatly reduce the negative effects of ongoing material production, especially related to petroleum-derived products. These adverse effects include the emission of harmful greenhouse gasses (CO_2), energy consumption, and the emission of toxic substances into the environment, among others.

Product development currently underway includes an important project designed to produce a new category of thermal insulation derived from a reed plant source. The Totora (Schoenoplectus Tatora) is an aquatic plant abundantly present in the Titicaca Lake basin between Bolivia and Peru. The results of various tests indicate that this natural material has a low thermal conductivity, revealing its insulation potential. Therefore, there is the possibility of benefiting from and enhancing the properties of this rapidly renewable regional material. Potential application of the material includes improving interior thermal comfort conditions of houses in the Andean high zone in Peru, where they are faced with extreme variations in temperature [24].

Colombian Passivhaus

Passivhaus solutions have been adapted around Latin America. A recent study proposes the use of bio-materials for the structure and insulation for a Passivhaus dwelling in Colombia [25]. They propose Guadua Angustifolia's structure, a local type of bamboo and hemp, as illustrated in Figure 8. Table 4 shows the construction system used in this project.

One of the designers' key findings was that the house could save up to 84.4% of the total primary energy demand compared to a traditional house in Colombia. Nonetheless, there was an increment of 24.3% in the construction cost. The materials proposed in this project, such as those made from Guadua Angustofilia and hemp insulation, are relatively new in the Colombian construction industry. However, with time these materials may become widely available, reducing their cost considerably.

Figure 8 Image of the Colombian solution for Passivhaus using Bio Materials. Source: [25]

Eco-material solution for Latam

Compressed Straw Boards (CSB) were developed in the Czech Republic with Swedish technology and marketed as Ekopanely. Our/Ecolution, a Swedish company, is investing in Uruguay set a CSB factory to manufacture and distribute CSB to Latam. Our/Ecolution boards offer construction boards that are ecological and vapour permeable. They are highly compressed straw at high temperatures creating a core of compressed straw using no bounding additives. They are then enclosed with cardboard following the BS 4046:1991 Standard. In addition to the carbon sequestration by using raw straw, the production of these panels has low CO_2 emissions making the Our/Ecolution board a negative carbon material.

These CSB panels are recyclable, fire-restraint, mechanically robust and have high levels of insulation and sound-dampness. The panels come in a wide variety of solutions for self-supported partitions (non-load bearing), installation self-supported partitions (non-load bearing), acoustic self-supported partitions (non-load bearing), interior and exterior partition (load-bearing), as well as interior cladding of ceilings and slanted walls. Ekopanley/ Our/Ecolution boards specifications accordingly to the manufacturer are described in Table 5.

Table 4. Construction detail of the Colombian solution for Passivhaus using Bio Materials. Source: [25]

Building element	Exterior Wall	Floor slab	Roof
Layer 1 (inside/ bottom)	10 mm plaster	100 mm reinforced concrete floor slab	10 mm plaster
Layer 2	11 mm OSB 4 [air-tight layer]	26 mm XPS insulation	10 mm Guadua Angustofilia
Layer 3	80 mm service void between Guadua Angustofilia battens	10 mm ceramic flooring	80 mm service void between Guadua Angustofilia battens
Layer 4	10 mm Guadua Angustofilia		10 mm Guadua Angustofilia
Layer 5	54 mm hemp fibre insulation		60 mm hemp fibre insulation
Layer 6	10 mm service void between Guadua Angustofilia battens		10 mm service void between Guadua Angustofilia battens
Layer 7	10 mm asbestos cement board		11 mm OSB 4 [air-tight layer]
Layer 8			
(Outside/top)			Humidity barrier and asphalt roofing tiles
U-value	0.537 W/(m^{2}K)	0.164 W/(m^{2}K)	0.147 W/(m^{2}K)

The compressed straw in Our/Ecolution boards enables them to accumulate heat. Therefore, buildings made of Our/Ecolution boards cope better with fast swings in temperature, saving on heating and cooling costs. Additionally, the Ekopanely boards make the construction easy and fast as they reduce on-site construction time leading to significant savings during

Table 5. Ekopanely specifications. Source: https://ekopanely.co.uk/

Specification	Ekopanely E40	Ekopanely E60
Thickness	38 mm	58 mm
With	800 mm	1.200, 800 mm
Length	1,200 – 3,200 mm	1,200 – 3,200 mm
Average basis weight	16 kg/m^2	22 kg/m^2
Average density	379 kg/m^3	379 kg/m^3
Thermal conductivity	0.099 W/(mK)	0.099 W/(mK)
Water vapour resistance factor (μ)	9.7	9.7
Fire response category	E	E
Determination of Volatile Organic Compounds	A+	A+

Figure 9 Detail of the Ekopanely board and placement. Source: https://www.ekopanely.eu/gb/

the construction phase. Finally, Our/Ecolution boards have excellent insulation and acoustic properties. They are an ecological product made from a sustainable raw material (straw) widely available in Latam.

Benefits and challenges

Decarbonising buildings across the entire lifecycle will require a systemic transformation of the buildings and construction sector. Reaching net-zero operational and embodied carbon emission buildings is possible but requires clear and ambitious policy signals to drive a range of measures, including passive building design, material efficiency, low-carbon materials, efficient building envelope measures and highly efficient lighting and appliances.

In addition to providing healthier, more resilient and more productive environments, the decarbonisation of the buildings sector presents a business opportunity in Latin America and the Caribbean with an estimated value of approximately USD 4 trillion by 2030 [26]. Decarbonising buildings is also in full alignment with the aims of SDG 12 to ensure sustainable consumption and production patterns.

Government and industry coalitions need to promote the adoption of existing efficient building construction and operation techniques and low-cost technologies that can improve building performance and lower embodied carbon [27].

Trends and Challenges in Latin America

- In LATAM, floor area is expected to grow 65% by 2050, including an additional ~11 billion m^2 of residential buildings by 2050[28]. Increasing incomes are also driving up floor area and appliance ownership per capita.
- Few countries, including Argentina, Brazil, and Mexico, have mandatory or voluntary codes within the sector, while other countries are developing the first building energy code [27].
- The informal sector is responsible for up to 75% of new housing.

Key challenges [29]:

- Develop national strategies to decarbonise new and existing buildings.
- Develop, implement and progressively strengthen mandatory energy codes that are integrated across relevant disciplines.
- Increase the access, training and use of energy performance design and modelling tools.
- Reduce embodied and operational carbon through materials and clean energy measures.
- Increase awareness of and information related to the myriad benefits of sustainable buildings.

It's time for action!

Latin American Passivhaus Institute

The Latin American Passivhaus Institute, or Instituto Latinoamericano Passivhaus (ILAPH) in Spanish, is a non-profit organisation (NGO) formed in 2019 by industry professionals from Latin America and Europe committed to providing leadership, education, training and certification across Latin America for the adoption of Passivhaus building performance standards and methodologies. ILAPH is a collaborative network that promotes the building industry's decarbonisation by implementing the Passivhaus Standard as established by the Passive House Institute located in Darmstadt, Germany. ILAPH is committed to a unified Latin America and currently has representatives in twenty (20) countries, including Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Puerto Rico, Peru and Uruguay.

Active collaboration and strategic partnerships

In addition to the Latin American Passivhaus Institute (ILPAH) existing network of Passivhaus Designers, architects and other professionals in the building sector, ILAPH has made strategic partnerships with key players in LATAM to achieve their goals. The ongoing network formation strategy is comprised of four (4) main elements including:

1. Establish a Local Chapter via a local CPHD/C
2. Form educational alliances with national universities and training facilities

3. Develop alliances with local Green Building Councils
4. Cultivates working relationships with local Professional Architect Associations

ILPAH is also working closely with the Capital Cities 35 (CC35) to achieve an accelerated impact of the Paris Agreement through the leadership of the major Capitals in the Americas. As such, ILPAH is playing an active role through the implementation of the Passivhaus Capital Cities programme establishing the Santiago (Chile) – Glasgow (UK) route in unity to the climate action plan of the COP25-COP26.

ILAPH is also supported by an international network of other Passivhaus Chapters in the Americas (North American Passive House Network and Passive House Canada | Maison Passive Canada) as well as Europe (Portugal Passivhaus). These collaborations seek to establish support for training and collaboration opportunities to achieve a sustained and successful implementation of the Passivhaus in LATM.

The time is NOW!

Our planet calls for help; we must act. *The time is NOW!* You can be a positive agent of change by being informed, engaging, and actively participating in the discussion of sustainable buildings, particularly desition and policymaking in your area. The Passivhaus has the potential to help climate change mitigation and impact the SDGs positively. Passivhaus buildings can incorporate natural materials. These materials help to develop further the construction industry in Latin America and making it resource-efficient.

Combining the Passivhaus with natural materials not only helps the environment and reduces CO2 emissions, more importantly, it *improves your quality of life and health*. Natural materials have the potential to regulate better indoor temperatures making the buildings more comfortable. Additionally, they have the benefits of regulating the moisuture in the building and the building structure. Finally, avoiding the use of synthetic materials, we avoid the off-gassing from building materials improving the indoor air quality.

To learn more about the Passivhaus developments in Latin America and how you could participate in shaping the future of the Standard, get in touch with us. We also encourage you to engage and actively participate in the *professional Passivhaus networks* in Latin America, such as LatamHaus and ILAPH. These networks have other members with similar interests that can help you develop ideas for projects and collaborate with professionals, academics, and policymakers.

Local and National governments should commit to exploring and developing strategies that incorporate mitigation actions in the building industry. The Passivhaus has shown significant benefits to reduce the impact of climate change. Countries such as Ireland had fully embraced the Standard on their building regulations. In Latin America, Mexico and Chile had incorporated some of the Passivhaus design methodologies on their National building regulations and 'eco-housing' programs.

The role of *academia* is essential not only to educate the new generations with a better perspective but also to inspire change and sustainable thinking within early ages. Additionally, researchers can inform and advise the government on policymaking desition setting the direction for a more resilient and unified Latin America. *Industry* innovation and development is vital to make available the process and materials needed for the change. Consumers drive the industry, so *the most critical factor for 'the change' is you!* We need to be more observant and demand more sustainable, healthier, *more resilient and more resource-efficient solutions for buildings*.

The team

Alejandro Moreno Rangel, Research Associate, Lancaster University

Alejandro's main research interests are sustainable architecture and its connections to health, urban and human behaviours. Alejandro explores the architectural design, energy efficiency methods, passive techniques and their impact on the indoor environment – indoor air quality (IAQ) and thermal comfort–, especially in homes and their relation to the urban environment to create healthy homes. Architecture has well responded to climate change mitigating the effects of the built environment. However, its impact on health is usually left aside. Alejandro's approach to architectural design seeks to improve the quality of life for all citizens in an ageing society, delivering sustainable interventions that take a "whole house" approach. Alejandro's research focuses on delivering healthier indoor environments through this approach, considering the impact of bio-psychological-social aspects of health, interactions between resident behaviours and the built environment, climate change impacts, and energy efficiency methods interactions. Alejandro's research interests also extend to the use of low-cost sensors as research tools and the effect that they could have on residential behaviour, design and human health & wellbeing. Alejandro is a Chartered Architect in the Americas, where he holds a practice developing residential projects. Alejandro studied at M.Arch with a pathway in Zero-Energy Mass Customised Housing at the Glasgow School of Art, where he also completed his PhD. Certified Passivhaus Designer (CPHD) in 2021.

Emmanuel Tsekleves, Senior Lecturer, Lancaster University

Dr Emmanuel Tsekleves leads Design for Global Health at ImaginationLancaster, Lancaster University. Driven by the UN's Sustainable Development Goals, his research focuses on tackling community health challenges worldwide. He is currently working on understanding cleaning practices and driving infections from homes in Ghana; developing health and care policies for senior citizens in Malaysia and in promoting seafood across Europe through novel packaging design. Emmanuel is Co-Director of the Future Cities Research Institute; a new cross-university and cross-discipline institute on urban research, between Sunway and Lancaster Universities aimed at making a major contribution to the international conversation on sustainable cities, helping to tackle significant challenges associated with the rapid urbanisation experienced across the Global South.

Juan Manuel Vazquez, Executive Director, ILAPH.

Juan currently serves as the founding Executive Director of the Latin America Passivhaus Institute (ILAPH). Graduated as an Agricultural Engineer from the Faculty of Agronomy of the University of Buenos Aires, since 2000 he ventures into the construction of houses with natural materials, first of all, raw earth, and then specialises in Compressed Agricultural Fiber. He is exclusively dedicated to building with highly energy-efficient Biological materials and recognised by Isobioproject. Coordinator of the Construction area within the Bioeconomy Program Faculty of Agronomy UBA. Passivhaus Consultant Course in November 2017. President of Ekosystem Consultoría y Desarrollo Real Estate Projects with high Ecological Standards and Near Zero Energy Building Passivhaus. Certified Passivhaus Designer (CPHD) and Passivhaus Trades Person in 2020.

Tyler Schmetterer, International Advisor, ILAPH

Tyler Schmetterer is a sustainable prefabrication expert based in Switzerland and New York with 30+ years of commercial experience. Tyler is currently the Managing Director of MOD X – a global consulting and knowledge exchange network in the prefabricated and volumetric modular offsite construction industry – and serves on multiple International Advisory Boards in the high-performance building, renewable energy and supply chain human rights sectors. In 2006, Tyler co-founded an advisory group, and award-winning producer of sustainable prefabricated buildings focused on designing and manufacturing high-performance green homes. The organisation advocates for universal collaboration, knowledge sharing and integration of world-leading performance standards and sustainability certification programs across the global offsite construction industry. To date, the venture has earned several historic U.S. environmental certifications and awards including the 1st USGBC LEED Platinum prefabricated home in NY, NJ and Georgia. Tyler earned a BA from Skidmore College (dual major), an MBA from Fordham University and completed the Passive House Consultant Program (CPHC) in 2014.

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