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Climate care through regenerative building practices

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Abstract. The built environment is one of the major drivers of environmental degradation due to its high production of CO_2 emissions and waste. Thus, the construction sector requires more radical solutions going beyond sustainability frameworks because how we build plays a crucial role in ensuring human comfort on the planet. In this paper, we introduce the concept of a Regenerative Built Environment (RBE), which holistically addresses the integration of socio-cultural and ecological systems. By prioritising nature-based materials such as timber, bamboo, and hemp, this approach embeds carbon within the built environment over the long term, thereby actively contributing to climate mitigation. However, several authors point out the necessity to focus on case studies to provide better guidance for implementation. We address this research gap by comparing two experimental buildings in Potsdam (Germany) and Bali (Indonesia) that applied regenerative building practices. We planned, designed, and built them as part of the ReBuilt project, which gives us good insights into their construction practices. Additionally, we developed a value-chain mapping to analyse the regionality of their materials and a Life Cycle Assessment (LCA) to show environmental impacts. The goal of this paper is to present insights for practitioners by asking how current construction practices can be disrupted to achieve regenerative buildings. When considering the production and transportation lifecycle stages A1-A4, both case studies show an exceptional environmental performance using regional nature-based or secondary material value chains, outperforming conventional buildings by more than 120%. The result of this paper is an implementation framework for regenerative buildings consisting of the following seven strategies: (1) working with a vision, (2) actively shaping legal frameworks, (3) focusing on regional value chains, (4) building local networks, (5) respecting place, (6) integrating vernacular knowledge and craftsmanship, and (7) utilising Design for Disassembly (DfD) methods. In short, regenerative building practices have the potential to actively care for our climate.

1. Introduction

In 2020, the total mass of human-made materials (anthropogenic mass) surpassed the planet's living biomass. A study by Elhacham et al. highlights that human activities, particularly the continuous production of buildings, infrastructure, and consumer goods, have altered the Earth and its natural systems in unprecedented ways. Over the last century, anthropogenic mass has doubled approximately every 20 years, now accumulating at a rate of 30 gigatonnes annually. In contrast, plant biomass, which declined from two teratonnes to one since the first agricultural revolution 3000 years ago, has remained relatively stable over the past century. Key factors

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influencing this shift include the mid-20th century transition from bricks to concrete, the rise of asphalt as the dominant road material, and various land-use changes such as deforestation and afforestation.[1] These trends underscore the increasing dominance of human-made structures over natural landscapes, demonstrating a profound transformation of Earth's surfaces.

Living in the Anthropocene, where climate change increasingly impacts societies and ecosystems globally, building methods will play a crucial role in ensuring human comfort on the planet. From a global point of view, construction is the most environmentally damaging sector, producing not only high amounts of CO_2 emissions but also enormous amounts of waste. In 2020, the built environment contributed 37% of global annual energy-related CO_2 emissions, including both embodied and operational emissions.[2] In Germany, for instance, 54% of the total waste produced in 2022 was attributed to construction and demolition.[3] Yet, the challenge lies ahead of us. By 2060, the global building stock is expected to double in size.[4] If conventional materials and methods continue to be used, this expansion will significantly increase climate impacts, which might lead to unprecedented cascading effects.

In this paper, we introduce the concept of a Regenerative Built Environment (RBE) that addresses the aforementioned critical developments and proposes the integration of nature and culture as a solution to the climate crisis. Regenerative development focuses on designing systems – such as buildings, cities, and infrastructure – that go beyond reducing environmental harm to actively restore and revitalise natural ecosystems. This approach seeks to transform the human-nature relationship into a collaborative and mutually beneficial partnership, fostering long-term ecological balance.[5] However, scholarly work points out the implementation gap of operationalising regenerative frameworks in construction and the necessity to analyse case studies to demonstrate practical implementation methods.[6] Therefore, in this study, we focus on two demonstrator buildings in Germany and Indonesia that were built as part of the ReBuilt project and follow the RBE concept. We participated in the planning, design, and construction of these buildings and analyse their realisation processes, create a value chain mapping of their building components, and a life cycle assessment (LCA) of the environmental impact of their materials from a product and transportation perspective (modules A1-A4). The central question we answer is: How can current construction practices be disrupted to achieve regenerative buildings? The goal is to present insights for practitioners that highlight the transformational changes needed to create a future building stock that is not only sustainable but also regenerative.

2. Towards a Regenerative Built Environment

Regenerative approaches to the built environment form a dynamic, multidisciplinary field of research with an expanding body of literature. Many scholars attribute the establishment of regenerative development and design as distinct disciplines to landscape architect John T. Lyle and his book *Regenerative Design for Sustainable Development*.[7] Regenerative disciplines have largely evolved from ecological and living systems perspectives, promoting a re-evaluation of humanity's evolution within ecological, technological, economic, and social frameworks.[8] Regeneration is a refreshing new approach for the built environment that extends beyond reducing harm. By reusing and recycling materials, but especially by using nature-based materials such as timber, bamboo, or hemp, this perspective seeks to store carbon in the building stock on a long-term basis, thereby actively mitigating the climate emergency. Building regeneratively means incorporating systems thinking, nature integration, circular economy principles, and just transition ideas to transform the sector into a force for positive environmental and social impacts.

This paradigm aims to dissolve the perceived divide between humans and nature, as well as between urban and rural areas, encouraging their reintegration and mutual evolution in a harmonious relationship.[9] The regenerative process starts at the macro scale (bioregions or landscapes) and extends down to local contexts emphasizing the importance of a historical, cultural, ecological, and economic understanding of the places of sourcing.[8] Thus, regenerative development advances the concept of sustainability by not only preserving but also revitalising ecosystems, integrating socio-ecological systems in a holistic manner.[10] Moving beyond conventional sustainability approaches, a regenerative approach opens new pathways for building practices that give more to the environment than they take.

Creating regenerative building projects requires a deep understanding of a place's unique identity, allowing for locally adapted solutions that promote long-term sustainability.[6] Rather than relying on standardised best practices, regenerative design emerges from the distinct characteristics of a location, restoring rather than depleting essential life-supporting systems and harmonising built and natural environments.[10]

Next to a strong focus on community engagement, regenerative design calls for an ongoing commitment to ecological and social stewardship over time that encompasses humans, other species, and ecosystems.[11] In this context, Cole et al. emphasize two key shifts in design thinking: (1) viewing buildings as evolving, adaptive processes rather than static objects, and (2) expanding the focus from individual buildings and their sites to the larger neighbourhood context.[12] Thus, regenerative design prioritises perceiving buildings as dynamic processes that evolve in response to local conditions, with a strong focus on meeting community needs.

Furthermore, regenerative architecture must remain flexible in responding to unexpected changes over time. Unlike nature, which can spontaneously adapt to external circumstances, the built environment requires intentional modifications to persist and evolve. Therefore, incorporating adaptability into the built environment is essential to regenerative design, reflecting the ever-changing dynamics of social-ecological systems.[12]

In summary, the following five key principles express the core characteristics of a RBE: (1) A holistic value chain approach considers the entire lifecycle of buildings and infrastructure. (2) Respect for place requires careful attention to the construction site as well as to the place of sourcing. (3) A positive environmental impact, achieved through incorporating renewable, recycled, or reused materials in construction. (4) Community engagement and stewardship ensure that built environments are taken care of over time. (5) Adaptability and resilience ensure that buildings are designed to respond to evolving environmental and social conditions. [13]

Critics of the RBE concept consistently highlight challenges in its practical implementation across multiple dimensions. Both Clegg and Tainter question the appropriate scale for application by pointing to a 'scalar contradiction' between the ambitious goals of regenerative design and the practical constraints faced by those executing projects.[14, 15] Similarly, Camrass underscores difficulties in operationalising regenerative frameworks. She highlights the absence of sufficiently detailed frameworks for engaging stakeholders across sectors, and the challenge of integrating regenerative goals and success metrics into existing planning and evaluation systems.[6]

3. Methodology

To gain an initial overview of the conceptual cornerstones of a RBE and current research trends, we conducted a literature review. In response to the implementation gap identified by several authors, we employed both qualitative and quantitative methods to analyse two case studies. We used three different methods to collect data. First, we collected information about the construction practices from colleagues and practitioners who were involved in the planning, designing, and construction of the pavilions. These inquiries focused on the materials used, exploring how they were sourced, fabricated, transported, and utilised in the building. Second, we mapped the value chains for each of the case studies' materials, indicating the sourcing locations and transportation distances, to better understand the regionality of the materials. Third, we performed an LCA analysis for the materials used in each building, focusing on the Global Warming Potential (GWP), and compared these findings with conventional materials in the respective contexts to evaluate the environmental impact using a baseline. We analysed the two buildings from a cradle-to-gate perspective including the transport emissions (A1-A4), because these stages cause the emissions that arise directly before and during the construction of a building without having to make assumptions about the end-of-life scenarios. Biogenic carbon is included in GWP modules A1-A3. The modules C3 and C4, in which the CO_2 is released back into the atmosphere through incineration or landfill – according to typical material datasets – were not considered in this study. For the Proto Potsdam pavilion, the GWP in the modules A1-A3 was calculated with the German eLCA Tool, based on the data of ÖKOBAUDAT OBD_2023_I_A2. For the BaleBio pavilion, the GWP in the modules A1-A3 were calculated using an internal Eco-Mantra tool based on data from EPDs, scientific articles, and the OneClickLCA database. For both demonstrator buildings, transport distances were evaluated partly based on information from our local partners and partly on assumptions using regional characteristics. Finally, we compared the results and derived further insights for practitioners to achieve regenerative buildings.

4. Case Studies

4.1. Proto Potsdam (PP)

Proto Potsdam is a small temporary pavilion located in Potsdam (Germany), serving as a laboratory for nature-based and circular construction. Situated on a continuously expanding demonstration site open to the public, the pavilion showcases cutting-edge research and hosts events and interdisciplinary discussions on the future of building. Its realisation is the result of a collective vision shared by all involved stakeholders. The pavilion was planned to be fully deconstructed at the end of its current building permit, which ends in 2028. Therefore, connections are only screwed while the structure using compressed earth blocks without any artificial binders can be given back to nature without causing any harm.

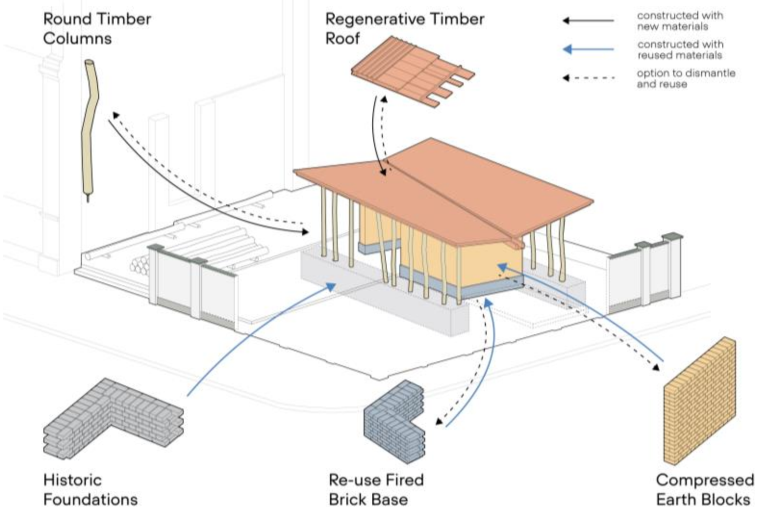

Figure 1. Demonstrator Building Proto Potsdam - details of all construction materials.

4.1.1. Construction Practices

Historical Foundations
The site was originally occupied by a half-timbered building from 1724, which was replaced by a multi-storey brick building in 1778. This building was destroyed during the Second World War and the site has been vacant ever since. To minimise the use of materials in the foundations, the design of the pavilion was adapted to the position and load-bearing capacity of the historic foundations. Therefore, the robinia columns were anchored to the historic strip foundations.

Reused Fired Bricks
Despite their popularity in Germany, where 30% of building projects use them, fired bricks require significant energy to produce, often from fossil fuels. In a regenerative construction context, bricks are of particular value as recycled materials. However, reclaiming them remains labour-intensive and costly. Thinking of buildings as resources can support decarbonisation. PP demonstrates this by using reclaimed bricks from a 19^{th} century farmhouse.

Compressed Earth Blocks
There is potential for innovation in the conventional extraction and disposal of mineral materials in the construction industry, particularly in Brandenburg, where 500,000 cubic metres of uncontaminated excavated material is wasted each year. This material can be used to produce unfired compressed earth blocks, a sustainable alternative to climate-damaging masonry. These blocks are fully recyclable, promoting circular building practices. The research led to the approval of an earth block made from excavated material from Berlin, which is now used in the load-bearing structure of the PP pavilion – for the first time in a building this size. Thus, an important legal step was made for disseminating the construction with compressed earth blocks.

Regenerative Timber Roof
Wood, the most common bio-based building material in the region, plays a key role in regenerative construction by sequestering carbon. Coniferous softwoods dominate due to their fast growth and ease of processing, but their monocultures in Brandenburg are vulnerable to climate change. A shift to mixed forests and regenerative management is needed. The PP pavilion explores alternative uses, including branch-rich sections, hardwood species, smaller logs and young wood.

Round Timber Columns
Round timber columns is a centuries-old technique, with Robinia wood chosen for its durability. While Robinia is highly weather-resistant, it lacks standard approval in Germany due to low demand and insufficient sawmill infrastructure, placing it in the lowest strength class for structural use. But PP demonstrates the untapped potential of Robinia wood in construction.

4.1.2. Value Chain Mapping
The Berlin-Brandenburg region offers a variety of locally grown resources. In the adjacent region to the PP building, around 37% of the land is covered by forest and sustainable value chains have been established, particularly for pine, which accounts for 70% of the region's typical tree species. Our analysis shows the regional nature of all the used construction materials – both renewable and reused (see Figure 2). The transportation distance is in no case longer than about 75 km to the site. This indicates significant potential for future nature-based buildings in the area.

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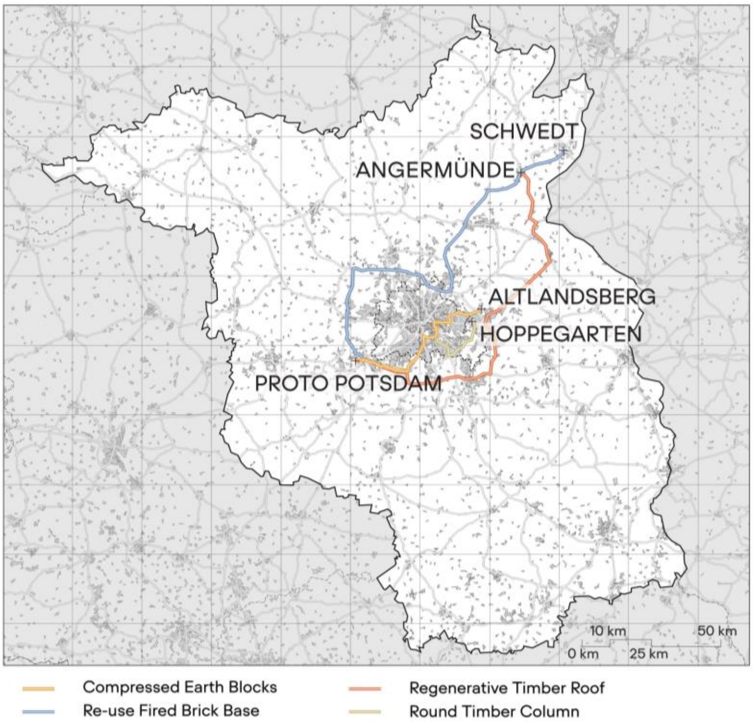

Figure 2. Proto Potsdam - value chain map.

4.1.3. Life Cycle Assessment (LCA)

PP shows that it is possible to store carbon in the building stock while significantly reducing embodied emissions for production and transportation by using regional, natural, and reused materials. The results of the LCA (A1-A4) show that the historic foundations did not cause new emissions, the reused bricks and the earth block walls have low emissions, while the round timber columns and the wooden roof store carbon as long as the components stay in the material cycle.[17] Compared to a conventional building, this is a difference of 121,5%. This means the pavilion not only neutralises its own emissions but offsets additional CO_2 beyond its own footprint.

Table 1. Comparison of lifecycle stages A1-A4 for PP using conventional and regenerative materials.

Building Type	Reference	Global Warming Potential					
Proto Potsdam	m^2 Gross Floor Area	kg CO_2 eqv. A1-A3	kg CO_2 eqv. A4	**kg CO_2 eqv. Total**	kg CO_2 eqv./m^2 A1-A3	kg CO_2 eqv./m^2 A4	**kg CO_2 eqv. / m^2 GFA Total**
Conventional	23	20.964	1.886	**22.850**	911	82	**993**
Nature-Based	23	-6.334	1.426	**-4.908**	-275	62	**-213**

4.2. BaleBio (BB)

BaleBio aims to connect rural agroforestry systems with rapidly growing urban centres in Indonesia, with the goal of implementing the concept and practices of a RBE across value chains. The demonstration pavilion, located on the island of Bali, explores the use of both nature-based and reused/recycled building materials, including innovations such as structurally engineered

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bamboo, as a sustainable alternative to emission-intensive materials such as cement and steel in urban construction (see Figure 3). The pavilion was constructed with its end of life in mind. All connections were screwed or bolted to be able to deconstruct or repair it with minimal effort.

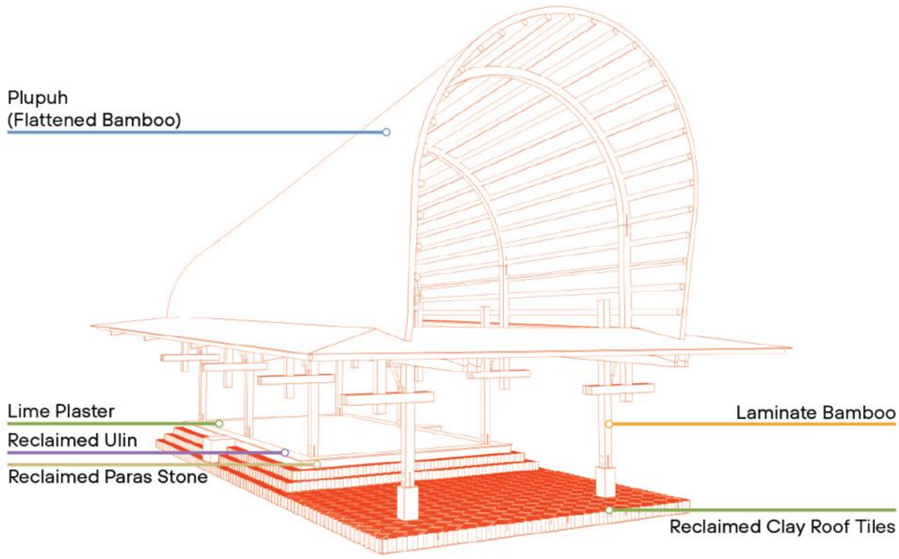

Figure 3. Demonstrator Building BaleBio - details of all construction materials.

4.2.1. Construction Practices

Reclaimed Paras Stones
Two shrines per household are typical in Balinese culture. These are traditionally carved from Paras stone, a local material praised for its durability and natural beauty. However, the carving process generates a significant amount of waste. When constructing BB, surplus Paras stones were collected from local stone carvers and reused for the podium of the pavilion.

Lime Based Floor Plaster
Lime-based plaster is a traditional and eco-friendly flooring material widely used in Bali. It is made by mixing finely crushed red clay bricks with lime to create a smooth, breathable, and durable surface. The lime content naturally regulates humidity, making it ideal for tropical climates, while its locally sourced ingredients reduce environmental impact.

Reclaimed Clay Roof Tiles
Clay roof tiles are a common feature of many buildings in Denpasar (Bali), valued for their durability and insulating properties. A significant number of tiles are often wasted during construction and renovation. By crushing and incorporating these reclaimed tiles, BB reduced construction waste and gave new life to a traditional material.

Reclaimed Ulin – Iron Wood
Borneo Ironwood, known locally as *Ulin*, is a highly durable and water-resistant hardwood traditionally used in construction throughout South East Asia. For the edge detailing of the podium, the construction team sourced reclaimed Ulin from a company specialising in sustainable timber. Their 100% recycled hardwood is salvaged from disused structures in Kalimantan, such as old houses, warehouses and bridges, ensuring that no new trees are cut down.

Laminated Bamboo
The BB uses laminated bamboo as its primary structural material, chosen for its strength and sustainability. On the island of Bali, it was used for the first time in construction. Furthermore, the pavilion will contribute to the translation of an international ISO-Standard (ISO23478) into Indonesian national standards. The structural components are made from *Dendrocalamus Asper*, a giant bamboo known for its durability and rapid growth. This bamboo is grown by village-based agroforestry collectives in Bajawa (Island of Flores), supporting local communities and promoting sustainable land use. Once harvested, the bamboo is processed into splits at the factory, where it is treated to increase its durability and resistance to pests. The treated splits are then transported to Bali where they are processed into high quality planks and beams. This multi-stage process makes it an alternative to traditional hardwoods or steel-concrete.

Plupuh – Flattened Bamboo
Plupuh is a traditional, low-tech method of processing bamboo by manually splitting and flattening culms into flexible planks. This technique has been used for centuries in Bali for construction applications due to its accessibility and durability. In the BaleBio, plupuh serves as the primary roofing material, with its layered sheets not only providing shelter but also contributing to the structural bracing of the building. The overlapping arrangement enhances strength while allowing for natural ventilation, making it well suited to tropical climate. Plupuh reflects local craftsmanship and strengthens the link between traditional building methods and contemporary regenerative design.

4.2.2. Value Chain Mapping
The bamboo value chain in Bali has evolved in response to rising demand from tourism and residential construction. Traditionally used in structures like panels, rafters, and roofing, bamboo remains a crucial material. Most locally sourced bamboo comes from adjacent rural areas on islands close to Bali. Inconsistent harvesting, such as cutting immature sections, often results in lower-quality material, which is then repurposed for secondary applications like railings and decorative elements. Beyond raw material supply, currently many vendors offer transportation and assembly services, making this sector increasingly accesible and profitable.

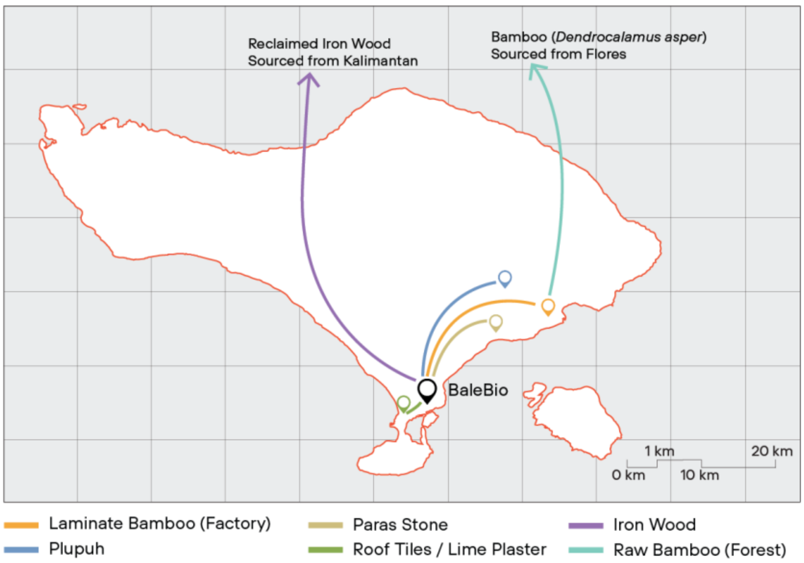

Figure 4. BaleBio - value chain map.

4.2.3. Life Cycle Assessment (LCA)
To minimise emissions from material transport and maximise the use of local resources, BB primarily uses materials from Bali and neighbouring islands in Indonesia. After performing the LCA calculations, the results show that the total emissions in the modules A1-A4 of the BaleBio pavilion are 121% lower compared to a conventional construction (See Table 2). More details about the conventional and nature-based materials used in the LCA calculations can be found in the supplementary data sheet.[17]

Table 2. Comparison of lifecycle stages A1-A4 for BB using conventional and regenerative materials.

Building Type	Reference	Global Warming Potential					
BaleBio	m^2 Gross Floor Area	kg CO_2 eqv. A1-A3	kg CO_2 eqv. A4	**kg CO_2 eqv. Total**	kg CO_2 eqv./m^2 A1-A3	kg CO_2 eqv./m^2 A4	**kg CO_2 eqv. /m^2 GFA Total**
Conventional	84	36.894	4.758	**41.652**	439	57	**496**
Nature-Based	84	-10.922	2.167	**-8.755**	-130	26	**-104**

5. Conclusion

We analysed two regenerative buildings in Potsdam (Germany) and Bali (Indonesia) with the aim to gain more insights for practitioners about how to disrupt current building practices to achieve regenerative buildings that actively care for our climate. Firstly, our research demonstrates that using regional, renewable, and reused or recycled materials can result in a drastically reduced carbon footprint for buildings (>120%), at least from a production and transportation perspective (lifecycle stages A1-A4). Secondly, and unsurprisingly, in both buildings the foundations are made from reused or recycled materials, while the above-ground structure is predominantly made from nature-based materials – principles that could be adopted in future building projects. Thirdly, both buildings activate and rely on regional networks and value chains, reintroducing vernacular knowledge, innovative materials and regenerative construction practices.

Several key characteristics of a RBE – as outlined in the literature review – are evident in the case studies demonstrating the integration of ecological and socio-cultural systems. A unified vision (RBE) to achieve a positive environmental footprint guided the development of both buildings. For that, both demonstrators incorporated new, innovative materials (PP: compressed earth blocks; BB: laminated bamboo). This suggests that the establishment of new standards and legal frameworks is necessary for future replication. The consequent regional sourcing of both renewable and reused materials in the case studies not only reduces transportation emissions but also highlights sustainable harvesting practices while fostering regional craftsmanship and vernacular knowledge. This underscores the need to build local networks for integrating vernacular construction elements (PP: robinia columns; BB: use of Plupuh and Ulin) and reuse strategies (PP: fired bricks; BB: Paras stones) as well as respecting place – both at the building site (PP: reusing historic foundations) and at the site of sourcing (BB: village-based agroforestry). An important aspect is the inclusion of Design for Disassembly (DfD), which influences construction methods (BB & PP: use of reversable connections). This aligns with the holistic value chain model and the vision to minimise environmental emissions through construction.

It is important to note that both case study buildings are experimental demonstrators that were realised as part of 'ReBuilt', an applied research project. They incorporate innovative components for the first time; therefore, they are not representative of standard housing or office development, which usually must fulfil acoustic, thermal, and fire resistance requirements. The comparative approach made it necessary to choose coherent lifecycle modules (A1-A4), which led to the exclusion of other modules: construction (A5), maintenance and use (B1-5), operational energy (B6-7), end-of-life stages (C1-4), and re-use potential (D). The LCA focus was on the indicator GWP and therefore environmental emissions, omitting other factors such as material efficiency, raw material consumption, and waste production. Nevertheless, the analysed pavilions show regenerative building practices serving as potential blueprints for future construction.

In summary, to answer the question of this paper, we have identified seven key strategies for achieving regenerative buildings: (1) working with a vision, (2) actively shaping legal frameworks, (3) focusing on regional value chains, (4) building local networks, (5) respecting place, (6) integrating vernacular knowledge and craftsmanship, and (7) utilising DfD methods.

6. Acknowledgements

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