From Local Traditions to Green Innovations: Construction Materials and Sustainability Trends in the Visegrád Four

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https://doi.org/10.29227/IM-2025-02-02-007

Submission date: *2025-05-30* | Review date: *2025-06-26*

Abstract

Construction materials reflect not only technological progress but also cultural heritage and environmental adaptation. In Central Europe, the Visegrád Four countries (Czechia, Hungary, Poland, and Slovakia) offer a unique case study in the transition from traditional materials such as timber, adobe, and stone to modern, eco-conscious solutions. Understanding this evolution is essential to evaluate how these countries are responding to climate challenges and EU sustainability goals. The aim of this study is to compare the historical and contemporary use of construction materials in the Visegrád Four, and to assess how these choices align with current sustainability practices, including energy efficiency, circular construction, and renewable energy integration. This research is based on qualitative comparative analysis of secondary data, national construction strategies, and case examples of public and private sector projects across the V4 region. Materials were classified chronologically—traditional, modernist/socialist era, and contemporary—highlighting shifts in usage, technological innovation, and ecological performance. Tables and charts were developed to illustrate patterns and trends. The findings show that while traditional materials like timber and brick remain prevalent in rural and heritage contexts, there is a growing adoption of sustainable materials such as cross-laminated timber (CLT), recycled concrete, and prefabricated panels. Czechia and Poland show advanced engagement in green certifications (e.g., BREEAM, LEED), solar integration, and smart glazing systems, while Slovakia and Hungary exhibit a slower, but visible transition. Challenges persist in the form of economic disparities, fragmented policy implementation, and social perception of older building types. The Visegrád Four countries are gradually transitioning toward greener construction practices, balancing historical identity with modern innovation. Material choices play a central role in this shift. Accelerating the adoption of circular and low-carbon materials can strengthen regional compliance with EU directives and contribute to more resilient, energy-efficient architecture. This comparative insight underlines the need for coordinated sustainability strategies tailored to each country's material legacy and socio-economic context.

Keywords: Visegrád Four, construction materials, sustainable architecture, green building, energy efficiency, CLT, recycled concrete, regional comparison

1. Aim of the paper

This study aims to compare the historical and contemporary use of construction materials in the Visegrád Four (V4) countries-Czechia, Hungary, Poland, and Slovakia—and to assess how these material choices align with current sustainability practices. The focus lies on three core areas: energy efficiency, circular construction principles, and the integration of renewable energy technologies.

Using a qualitative comparative framework, the study analyses secondary data, national strategies, and representative examples from both public and private sectors. Construction materials are examined across three historical phases—traditional, socialist/modernist, and contemporary—to illustrate shifts in usage, technological advancements, and environmental performance. The study concludes with recommendations for strengthening the integration of sustainable materials in V4 construction, while accounting for regional challenges and development opportunities.

2. Methodology

The study adopts a qualitative comparative analysis (QCA) approach, integrating literature review, analysis of national policy documents, and case study evaluation. Sources include academic publications, EU and national reports, and sustainability certification frameworks such as LEED, BREEAM, and SBToolCZ. [4, 5]

To trace developments over time, construction materials are categorized into three chronological phases:

- Pre-industrial traditional construction (up to 1945)
- Modernist-socialist mass construction (1945–1989)
- Contemporary sustainable approaches (post-1990)

This periodization enables both historical continuity and regional differentiation to be assessed. A sustainability scoring rubric—based on carbon footprint, recyclability, thermal performance, and policy alignment—is used to evaluate the ecological value of each material type.

To ensure methodological rigor, the study triangulates official datasets (e.g., LEED/BREEAM project registries), policy white papers, and on-site field observations in both rural and urban environments across the V4. These are supplemented by interpretive analysis to deepen the understanding of the technical, cultural, and political aspects of material use.

3. Introduction

Construction practices in Central Europe reflect a complex interplay between local traditions, political regimes, and evolving technologies. In the Visegrád Four (Czechia, Hungary, Poland, and Slovakia), this dynamic is especially visible, shaped by centuries of vernacular architecture, the industrialization and standardization of the socialist era, and the recent influence of EU sustainability frameworks.

The Visegrád Group, established in 1991, was created to promote political, economic, and cultural cooperation among the four nations during their transition from centrally planned economies to market-based democracies. Since then, regional collaboration has extended into the fields of urban planning, infrastructure, and sustainable development.

Understanding the trajectory of material usage across these countries provides insight into how architecture reflects shifting socio-economic and environmental priorities. From timber framing and adobe to prefabricated concrete and smart composites, materials serve not only functional purposes but also signal broader transitions in identity, policy, and culture.

This paper examines how material strategies in the V4 have evolved over time, exploring the balance between tradition and innovation. It also assesses the extent to which construction materials in the region support the broader objectives of climate resilience and EU-aligned sustainability. The V4, as this paper argues, should not be viewed as passive recipients of external sustainability models, but as active laboratories of regionally adapted, ecologically conscious construction practices.

4. Traditional Construction Materials

Building material – materials used for construction, repair, maintenance and modernization of structures.

The division of construction materials can be done in several ways such as according to:

- purpose into: structural, insulation and installation.
- the type of material: stone, silicate, ceramic, concrete, wood, metals, plastics, etc
- use for building elements: wall, floor, roof, etc.

Before the industrial era, construction in the V4 region was largely determined by local climate, resource availability, and artisanal traditions. Materials such as timber, adobe, limestone, clay tiles, and straw were commonly used, with regional adaptations reflecting environmental conditions and cultural practices.

In Poland, for example, timber churches in the Podhale region and red-brick manors in Mazovia illustrate both material adaptation and aesthetic expression. Czechia is known for log houses and stone farmsteads across Bohemia and Moravia. Slovakia and Hungary relied extensively on adobe, thatch, and compacted earth, particularly in rural and lowland regions.

These traditional materials provided several ecological benefits. Naturally sourced and biodegradable, they offered good thermal insulation and minimal embodied energy. However, limitations included vulnerability to moisture, fire, and structural degradation—leading to increased maintenance needs.

Today, there is a growing movement to preserve and revive traditional construction techniques, both for their cultural value and environmental performance. Eco-restoration initiatives and tourism-driven conservation projects are helping to reintroduce timber, stone, and clay as viable low-carbon alternatives in rural development and heritage renovation. [3]

Tab. 1. Summary of key materials and examples by country.

Country	Key Traditional Materials	Notable Examples
Czechia	Stone, timber, clay bricks, plaster/stucco	Charles Bridge, timber homes in Krkonoše
Hungary	Adobe, volcanic stone, thatch	Buda Castle Hill, reed roofs near Lake Balaton
Poland	Timber, stone, clay bricks, wattle & daub	Wooden churches (Małopolska), Malbork Castle
Slovakia	Stone, timber, adobe, shingle roofs	Spiš Castle, wooden churches in Orava and Liptov

Despite the predominance of modern materials, these traditional techniques are seeing renewed relevance, especially in sustainable tourism, heritage architecture, and rural regeneration programs.

5. Socialist-Modernist Materials and Mass Construction

The post–World War II era brought dramatic change to the built environment of the V4 countries. Under socialist regimes, urbanization and industrialization were accelerated to meet urgent housing needs. The dominant response was mass construction using prefabricated reinforced concrete panels—manifested in paneláky (Czechia, Slovakia) and wielka płyta (Poland). [1]

These systems enabled rapid, cost-effective construction but at significant environmental and architectural cost. Standardized designs prioritized quantity over quality, resulting in limited architectural diversity, poor thermal performance, and heavy reliance on energy-intensive materials.

Typical materials of the era included:

- Reinforced concrete (used in prefabrication and load-bearing systems)
- Asbestos-cement products (later banned)
- Aluminum sheeting and PVC elements
- Synthetic insulation of varying quality

Key characteristics of this period included:

- Emphasis on quantity over quality
- Uniform architectural style with limited local adaptation
- Environmental externalities overlooked during design and production
- Low thermal comfort and energy efficiency

Despite their shortcomings, many of these buildings remain in use and are now being retrofitted to meet energy efficiency standards. Their cultural and historical significance is also being reassessed, with growing interest in adaptive reuse and architectural rehabilitation.

This period presents both a challenge and an opportunity: retrofitting socialist-era housing offers significant potential to improve energy performance while reinterpreting architectural identity through sustainability.

6. Contemporary Materials and Green Innovation

Since the early 2000s, a slow but steady transformation has taken place in V4 construction practices, largely driven by EU policy alignment, environmental awareness, and participation in international certification systems such as LEED, BREEAM, and SBToolCZ.[5]

A new generation of construction materials has emerged, emphasizing:

- Cross-laminated timber (CLT): increasingly popular in Czech and Polish urban projects for its strength, carbon sequestration capacity, and aesthetic appeal. [2]
- Bio-based materials: including hempcrete, straw panels, and mycelium composites, particularly in Slovakia and Hungary.
- Recycled aggregates and low-carbon concrete: supporting circular construction goals in both new builds and retrofits.
- Smart technologies: such as building-integrated photovoltaics (BIPV), thermochromic glazing, and phase-change insulation for enhanced energy performance.
- Modular and prefabricated systems: used in passive housing developments to reduce material waste and on-site emissions.

While concrete and brick remain widespread, especially in urban areas, sustainable alternatives are gaining momentum. Notably, glass and aluminum continue to be favored in commercial construction, but their environmental footprint is now more carefully considered through life-cycle assessments and integration with green technologies. Progress across the V4 is uneven. Czechia and Poland lead in implementing innovative materials and green standards, whereas Slovakia and Hungary remain focused on small-scale or academic pilot projects.

Tab. 2. Sustainability Properties of Selected Materials

Material	Carbon Footprint	Recyclability	Insulation Value	Notes
CLT	Low	Medium	High	Expanding in V4 urban public projects
Recycled Concrete	Medium	High	Medium	Key for urban retrofit strategies
Hempcrete	Very Low	High	Medium	Ideal for low-rise, low-carbon construction
Straw Panels	Very Low	High	High	Featured in sustainable housing demonstrations

[a] Sustainability properties of selected construction materials commonly used or emerging in V4 countries, highlighting their ecological advantages.

By combining local material traditions with modern ecological principles, the V4 countries are beginning to reframe construction as a climate mitigation tool rather than an emissions source.

7. Comparative Insights: V4 Material Strategies

Although the V4 countries share similar climatic and architectural histories, their approaches to sustainable construction diverge based on political will, public awareness, and economic context.

Tab. 3 Comparative Summary of National Material Strategies

Country	Green Certification Engagement	Public Awareness	Government Incentives	Material Innovation Use
Czechia	High (BREEAM, SBToolCZ)	Medium–High	Moderate	CLT, modular design, PV glazing
Poland	High (LEED, passive housing)	High	Moderate	Recycled concrete, smart envelopes
Slovakia	Medium	Low	Weak	Hempcrete, straw bale (limited adoption)
Hungary	Low	Low	Limited	Primarily in academic or pilot initiatives

[b] Comparison of sustainable construction strategies across V4 countries, focusing on certification, policy engagement, and innovative material use.

Several cross-cutting challenges hinder the widespread adoption of sustainable practices:

- Lack of skilled labor familiar with new materials and technologies
- High upfront investment costs for sustainable alternatives
- Fragmented or inconsistent national policy frameworks
- Limited public knowledge and skepticism, especially in non-urban areas

Despite these barriers, EU Recovery and Resilience Funds offer new opportunities for innovation and public-private collaboration. Local governments are beginning to integrate green criteria into tenders, while grassroots movements and research centers promote regionally adapted sustainability practices.

The V4 region, though heterogeneous in pace and policy, shows increasing potential to align with EU environmental goals through material innovation, education, and strategic cooperation.

8. Renovation and Retrofitting: The Case of LPS Housing

One of the most pressing sustainability challenges in the V4 countries is the modernization of prefabricated housing blocks—commonly referred to as Large Panel System (LPS) buildings. Constructed primarily between the 1950s and 1980s under socialist regimes, these structures continue to house millions of citizens across the region. Although often criticized for their monotonous aesthetics and poor thermal performance, LPS buildings represent a significant opportunity for energy retrofitting and climate-responsive urban regeneration.

In some cities, LPS buildings account for over 30% of the housing supply. While these structures are often criticized for their monotony and energy inefficiency, they also present a unique opportunity for large-scale retrofitting, urban regeneration, and social revitalization.

Current renovation approaches include:

- Czechia: Programs like *Panelák Reborn* have focused on façade insulation, window upgrades, and smart metering.
- Poland: Thermomodernization initiatives target roof insulation, ventilation, and centralized heating modernization.
- Slovakia: Supported by EU funds, deep renovation projects address thermal performance and structural longevity.
- Hungary: Despite high LPS prevalence, retrofitting efforts remain limited and lack coordinated national policy support.

Tab. 4 LPS Renovation Actions by Country

Country	% Urban Population in LPS	Key Retrofit Actions
Czechia	~25%	Façade upgrades, smart meters
Poland	~30%	Roof and system insulation, heating overhaul
Slovakia	~32%	Deep EU-funded renovation programs
Hungary	~35%	Minimal upgrades, ongoing policy reform efforts

[c] Renovation measures for LPS housing blocks in the V4 region, showing the variation in retrofit strategies and implementation progress.

Beyond energy savings, successful retrofits also enhance living standards, reduce maintenance costs, and contribute to the social revitalization of entire neighbourhoods. They represent a pivotal intersection between past mass housing policies and future green infrastructure strategies.

9. Innovations and Future Technologies

The construction sector across the V4 region is beginning to embrace innovative technologies that align with EU climate goals and circular economy principles. These efforts, while still emerging, demonstrate the region's growing capacity for forward-thinking design and material science.

Key trends include:

- AI-supported Building Information Modeling (BIM): Used for energy simulations, material lifecycle analysis, and efficient project coordination. [7]
- Circular construction systems: Modular wall panels and assemblies designed for disassembly and reuse.
- 3D printing in construction: Pilot projects for housing and emergency structures using recycled or bio-based materials.
- Experimental bio-materials: Including cork insulation, mycelium bricks, and lignin composites with promising thermal and structural properties.

Selected projects include:

- Slovakia: The country's first 3D-printed house (Košice, 2024) demonstrates additive manufacturing potential in housing.
- Czechia: CLT-based offices in Brno's Science and Technology Park exemplify wood innovation in commercial construction.
- Poland: A passive kindergarten in Kraków or Podkowa Lesna, constructed from reclaimed materials, illustrates municipal leadership in sustainable design.
- Hungary: Experimental housing using straw insulation and mycelium-based panels is underway in academic institutions.

These innovations show that the V4 region is not merely adapting to sustainability trends, but increasingly contributing to them—blending tradition with experimentation in ways uniquely tailored to local contexts.

10. Case Studies

To illustrate the regional implementation of sustainable construction principles, several emblematic projects from the V4 countries are presented below. These examples highlight how public and private sector actors are integrating innovative materials, green certifications, and climate-adaptive design strategies.

- National Technical Library (Prague, Czechia):

The first LEED Gold-certified building in the country, it combines recycled concrete with adaptive glazing and efficient lighting systems [5]. The building showcases how public infrastructure can lead the way in sustainable design without compromising functionality or aesthetics.

- Nowy Rynek Development (Poznan, Poland):

This mixed-use project features prefabricated, energy-efficient façade panels, rainwater harvesting, and a pedestrian-oriented urban plan. It demonstrates how large-scale commercial development can align with circular economy principles and passive design strategies.

- Wood City (Budapest, Hungary):

An urban infill project utilizing cross-laminated timber (CLT), Wood City promotes carbon storage, short construction timelines, and biophilic design in a dense metropolitan context. It serves as a regional model for sustainable mid-rise timber construction. [2]

- Passive Kindergarten (Podkowa Lesna, Poland):

Built almost entirely from reclaimed and low-impact materials, this public kindergarten integrates passive heating and ventilation systems. It reflects growing municipal interest in sustainable public buildings and serves as an educational tool for future generations.

These case studies exemplify how sustainable materials and technologies can be adapted to the V4's architectural, climatic, and economic realities. Each project reflects both innovation and sensitivity to local context—demonstrating that sustainable construction need not be limited to high-cost flagship buildings.

11. Challenges and Barriers

Despite growing awareness and examples of good practice, several structural and institutional barriers continue to slow the widespread adoption of sustainable construction in the V4 countries. These challenges can be grouped into five main categories:

a) Economic Disparities

Uneven development between urban and rural regions hinders investment in sustainable materials and technologies. Small municipalities and private developers often lack the capital or incentives to pursue green construction.

b) Regulatory Gaps and Policy Fragmentation

While EU directives have been transposed into national law, actual enforcement and coordination remain inconsistent. In countries like Slovakia and Hungary, overlapping jurisdictions and shifting policy priorities complicate long-term planning and execution.

c) Workforce and Educational Limitations

The construction sector suffers from an aging workforce and outdated vocational training systems. There is a noticeable shortage of professionals trained in energy-efficient construction and emerging green materials.

d) Public Awareness and Cultural Perception

Sustainable buildings are still often perceived as experimental, expensive, or aesthetically unconventional. In rural areas, traditional construction methods dominate, and the environmental benefits of innovation are not widely understood.

e) Limited Interdisciplinary Collaboration

A lack of cooperation between architects, engineers, urban planners, and policymakers impedes integrated solutions. Many projects continue to treat sustainability as an add-on rather than a design foundation.

Tab. 5. Key Sustainability Challenges and Opportunities

Challenge	Root Cause	Potential Opportunity
Skills Shortage	Aging workforce, outdated education	EU-funded training and upskilling programs
High Green Material Costs	Limited regional production	Stimulate local manufacturing and innovation clusters
Policy Incoherence	Institutional silos, electoral cycles	Establish V4 Green Construction Councils for cross-border policy
Awareness Gaps	Weak outreach in non-urban areas	Housing cooperative–led education and demonstration projects

[d] Common barriers to green construction adoption in the V4, and proposed opportunities to overcome them through policy, education, and investment.

Addressing these challenges requires a dual strategy: top-down policy alignment and bottom-up innovation and education. The V4 region holds significant untapped potential—if strategic reforms are embraced across sectors, it can become a leader in context-specific sustainable construction within the EU.

12. Recommendations

Based on the comparative analysis, challenges, and case studies explored in this paper, the following recommendations aim to accelerate the transition to sustainable construction across the V4 countries:

a) Strengthen National Incentives for Green Materials - Expand tax relief, grants, and preferential loan schemes for developers using certified low-carbon and circular materials. Public procurement guidelines should prioritize sustainable solutions, especially in infrastructure and housing.

b) Integrate Circular Economy Principles into Legislation - Construction codes should include mandates for recyclable content, disassemblable systems, and material passports. Public sector projects can lead by example through circular design procurement standards. As previously outlined in Polish BIM policy documents [6], standardized procurement procedures are critical to enabling digital construction workflows across public sector projects.

c) Expand Interdisciplinary Education and Training - Universities and technical schools should update curricula to include BIM, lifecycle analysis, and sustainable material science. Joint programs between architecture, engineering, and environmental studies can improve workforce readiness.

d) Invest in Local Green Material Manufacturing - Encourage regional production of CLT, hempcrete, straw panels, and recycled aggregates to reduce dependency on imports and lower costs. Investment in green supply chains also creates local employment opportunities.

e) Foster Regional Cooperation and Knowledge Sharing - Establish V4-wide platforms for research exchange, certification harmonization, and pilot project dissemination. Coordinated policy development across the V4 could reduce duplication and amplify regional innovation.

These steps can help bridge the gap between high-level EU climate goals and the material realities of construction in Central Europe, making sustainability both actionable and scalable.

13. Conclusion

Balancing Tradition and Innovation

The Visegrád Four countries possess a rich architectural heritage and an emerging capacity for innovation. Their construction trajectories reflect a nuanced evolution: from vernacular materials rooted in cultural landscapes, through socialist-era mass industrialization, to contemporary sustainability imperatives. This layered legacy presents both a challenge and an opportunity—to create buildings that are environmentally sound, culturally grounded, and socially responsive.

Sustainability as a Strategic Priority

Engagement with EU directives, certification schemes, and climate policy instruments signals increasing alignment with sustainability goals. Material selection plays a pivotal role—not only for energy performance and circularity, but also for reinforcing regional identity in the face of globalization. The resurgence of timber, brick, and stone, alongside the introduction of cross-laminated timber, hempcrete, and recycled concrete, reflects this dual commitment.

LPS Retrofitting as a Turning Point

Renovation of large-scale prefabricated housing—particularly LPS buildings—is both a technical and societal imperative. These interventions represent the region's most impactful opportunity to lower emissions, enhance living standards, and showcase systemic green transformation. Programs like Panelák Reborn and national thermomodernization schemes demonstrate scalable pathways toward energy efficiency and social equity.

Innovation through Adaptation

Despite disparities in policy capacity and innovation uptake, the region is developing models of sustainability that are uniquely its own. From passive kindergartens built with reclaimed materials to 3D-printed houses using local resources, the V4 countries are not merely adopting Western green technologies but adapting them to fit local climates, traditions, and economies.

BIM as a Catalyst for Modernization

Though still nascent, Building Information Modeling (BIM) holds transformative potential for the V4 construction sector. By enabling integrated design, cost efficiency, and life-cycle assessment, BIM can facilitate better material decisions and project outcomes. Wider adoption—supported by education and regulation—can act as a lever for modernization and sustainability.

Looking Ahead

The V4 construction sector is no longer passively reacting to imported sustainability trends. It is instead evolving toward a self-defined paradigm—one that blends material awareness, innovation, and policy engagement. With continued investment in green technologies, workforce development, and regional cooperation, the V4 region is well positioned to become a leader in sustainable architecture tailored to Central Europe's unique environmental and cultural context.

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