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The Hidden Journey of Construction Materials: Insights from Experimental Pavilions of Vegetarian Architecture in Northern Italy

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Abstract. This paper examines the origins of construction materials, drawing on first-hand data from two Experimental Pavilions of Vegetarian Architecture in Northern Italy. The proposed prototypes aim to be rooted in locality and prioritize low-embodied carbon materials. The study highlights key challenges in tracking the exact origin of materials, and in effectively minimizing transport distances. Market conditions often force a compromise between sourcing in proximity and selecting low impact materials, which remain a niche segment. The assessment reveals that bio-based and low carbon geo-based materials are relatively straightforward to trace, while highly processed products pose greater challenges. Beyond transport distances, the research expands the concept of "localness", exploring the economic flows of the construction to illustrate the potential socio-cultural implications of design choices in reinforcing local economies.

1. Introduction

This study explores the concept of '*localness*' in the application of regenerative construction techniques. While it seeks to quantify material procurement distances and trace economic flows through a case study approach, it also raises critical questions about how the term itself should be defined. What constitutes localness in the 21st century? Is it defined by geographic proximity, administrative boundaries, environmental factors? How can localness be effectively measured?

1.1. New vernacular and localness

The conceptual framework on which this study is based upon is Bocco and Habert's definition of a 'vernacular architecture of the 21st century' [1]. Their theoretical proposal may be summarised in four criteria; a 'new vernacular' building should:

i. be mainly made of/with locally available resources;
ii. have a very low environmental footprint;
iii. meet real expectations of contemporary users; and
iv. be intended for ordinary, local people.

Such principles are founded on the earlier concept of "vegetarian architecture", which is in itself inspired from ecologically oriented agriculture and nutrition [2]. This theoretical stance advocates:

- building with natural, renewable, locally available construction materials, minimally processed and free of toxic chemicals [3–6];
- minimising the use of energy intensive, high-tech components (which may, however, be employed to achieve otherwise unattainable performance);

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- prioritising labour-intensive, small-scale production methods, simple constructional technologies, and passive solar design.

The concept of 'vernacular architecture of the 21st century' is an outcome of the vegetarian architecture concept but takes a more explicit reference to the socio-economic territorial system and the popular character it would embody. It also draws on current trends towards food sovereignty and self-sufficiency which may end up in reactivating trusted, fair and organic supply chains.

It shows therefore a research direction for designers, builders and clients to make with what is local; it is also an appeal to relocate production and to creatively develop new technical solutions and social arrangements.

Among other topics, then, authors advocate for a grounded architecture that supports a fair and circular economy by rethinking the definition of "local." While traditional vernacular architecture used nearby materials out of necessity, modern transport reduces the environmental impact of moving goods, making "local" more flexible today. Rather than strictly limiting material sources, the emphasis is on using locally available resources when feasible, much like prioritising local food without excluding fair-trade imports. Crucially, material choices should consider social and economic impacts: using local materials and skills can strengthen local economies, reduce reliance on fossil fuels, and redirect financial flows away from global corporations. Additionally, incorporating agricultural byproducts into construction could foster regenerative and economically resilient systems, supported by future policies and investment. [1]

The challenge of determining whether a building meets this criterion remains unresolved. Buildings and much more so local systems are inherently complex. Moreover, when evaluating a building's material origins, it is essential to recognise that buildings are deeply intertwined with their specific context, which can vary greatly from one situation to the next. Nevertheless, attempting to quantify certain aspects could help to uncover key factors that emerge from the distinct challenges and opportunities of each case. This would identify critical areas to advance the cause and advocate for its value. Such an approach could provide a methodological framework, without the need to standardise or homogenise cases, as doing so would contradict the very principle that underpins the analysis.

1.2 Case study: Experimental Pavilions of Vegetarian Architecture

The case studies are two one-storey pavilions built as part of the research project "Experimental Pavilions of Vegetarian Architecture" developed at DIST (Politecnico di Torino). The goal of the project is to construct full-scale prototypes that serve as living field laboratories for regenerative building techniques. The underlying principles are aligned with the concept of Vegetarian Architecture [2] – from which it derives its name.

The research is expected to lead to a deeper scientific understanding of the construction techniques employed and of the use of bio-based materials through comparative analyses of the field performance of the pavilions, and to highlight data on the construction market in the region. The respective building techniques derive from previous research on ecological exemplary buildings [2,7]. Locally available materials have been prioritised. The construction activity is carried out through training workshops with the help of local craftsmen at a site located about 9 km west of Torino. Two pavilions have been built: loadbearing strawbale and light earth infilled timber framed. Each pavilion has a gross internal area (GIA) of approximately 30 m^2. They share the same orientation, have similar layouts, volumes and openings, and exhibit comparable thermal performance. No building services have been planned except electricity.

The strawbale pavilion draws on extensive research [8–12] and references the work of the Swiss architect Werner Schmidt [13,14], who was consulted for the project. It rests on twelve Luserna stone blocks[1] topped by a chestnut beam grid. Two timber box slabs filled with straw bales form the ground floor and roof – the latter extending 80 cm beyond the walls and supporting a green roof over a ventilated gap created with 15 cm chestnut joists. Load-bearing straw bale walls are pinned with hazel sticks, lime-*cocciopesto*[2] rendered outside, and clay plastered inside over jute mesh. The floor is a lime and *cocciopesto* mix. Two 5 m^2 triple-glazed French doors with laminated bamboo frames are placed on the east and west façades.

The light earth pavilion is based on a timber frame infilled with a mixture of clay and straw on battens – an approach reminiscent of traditional wattle-and-daub – combined with an internal insulation layer, inspired by the work of German architect Franz Volhard [15]. The gabion foundation rises 45 cm above ground and is filled with 50–100 mm recycled aggregate from a facility 17 km away. The timber structure uses untreated local larch. The ventilated floor, enclosed by larch boards, is insulated with 30 cm of reed mats. Walls consist of 15 cm light earth (density 300–1000 kg/m^3 based on exposure) plus 15 cm reed mat insulation inside, finished with natural hydraulic lime outside and clay plaster inside. The single-pitch roof mirrors this, with 15 cm light earth and 5 cm reed insulation between larch boards. Larch shingles on battens form a ventilated roofing layer. Two 4.6 m^2 triple-glazed French doors with local wood frames are placed on the east and west façades.

While the Vegetarian Pavilions represent a unique case study with its own limits arising from the research focus of the project, examining them through this criterion is valuable for two primary reasons. First, they embody a design and construction process that actively considers the values underlying the principle discussed. Exploring these aspects in more detail helps assess the practical transferability of these principles. Second, the high level of control over first-hand data enables the collection of high-quality foundational information – something that would be difficult to achieve with other case studies, especially when the assessment is conducted after the buildings are completed. Monitoring construction processes is time-consuming, and acquiring such data is often challenging, even when designers and builders are willing to share it.

2. Methods and data

The assessment explores two main aspects. The first concerns the origin of the buildings, which involves breaking down each building component and tracing the material flows and their journey to the construction site. The second aspect focuses on evaluating the financial flows of the construction process.

2.1 Data investigation and inventorying: materials origins

All building components were included in the analysis. Three categories were investigated to trace the origin of the construction materials used in the pavilions: suppliers, manufacturers, and raw material sources. The depth of available data and the methods of acquisition vary considerably across these categories.

Supplier data were collected from invoices and site records, while manufacturer details were traced through suppliers. Raw material sources were investigated via manufacturers, with some

[1] a type of gneiss sourced in the Alps, approximately 50 km SW of Torino.

[2] crushed terracotta, tiles or brick fragments.

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data publicly available and others difficult to obtain – even through direct contact. Challenges depended on product complexity; proprietary compositions made some materials hard to break down, thus labelled as 'mixed/unknown'. Where raw materials were identifiable, but source locations unclear, distances were estimated using statistical averages. When manufacturers used multiple sourcing locations, a kilometric radius – either provided or estimated – was applied. For the French doors, a simplified model was used: the producer is the supplier, while manufacturers are those producing laminated timber and bamboo (frame), and glass (glazing).

2.2 Cost breakdown structure and categorisation

The project costs are divided into the following components, adapted to the specific case studies from the categorizations proposed in previous studies [16–19]:

- material purchasing costs
- labour
- transportation costs for all materials and equipment
- equipment cost, including tools, personal protective equipment (PPE) and rentals
- utility and site maintenance costs (electricity, water, waste disposal, maintenance)
- taxes (VAT for materials, tools, PPE and transport)

Costs are calculated based on the respective invoices. Transport costs are reported separately when this is declared by the supplier. The cost of materials provided through sponsorship is estimated using average market prices.

In conventional projects, indirect costs – covering general operations and support of the construction company – represent a significant portion of total expenses. However, in this case, run by a research institution, such costs are not directly applicable and are difficult to quantify without resorting to assumptions. For example, university staff managing administration and safety did not track hours, as the project was not funded by competitive grants. While estimating the contribution of on-site personnel (e.g., PhD students) would be feasible, it would capture only a fraction of the indirect costs. Given these unique conditions, indirect costs are not significant or comparable to those in standard construction projects.

3. Where do the pavilions come from? Tracing the path from sourcing to site

3.1. Suppliers and manufacturers

In selecting materials that were both low-impact and locally sourced, decisions were made by weighing multiple criteria and evaluating each case individually. Although minimizing transport distances was a priority, many materials were unavailable within a desirable range. Immediate availability in sufficient quantities was also essential, as most of the project's budget was subject to tight spending deadlines.

This urgency coincided with a difficult period for the Italian construction sector, marked by limited material supply and inflated prices due to the surge in renovations under the *Superbonus 110 scheme* [20–22]. Procurement procedures for public institutions added another layer of complexity, being lengthy and often unsuitable for smaller suppliers.

Italian-made products were generally favoured over imports, even if that meant longer transport distances. For bulk materials, environmental impact and quality often outweighed proximity. In the case of design-specific components, supplier options were limited and frequently far from the site. Cost considerations were also key, as staying within budget remained a constant challenge.

The suppliers are located within a radius of 512 kilometres from the site (Figure 1).

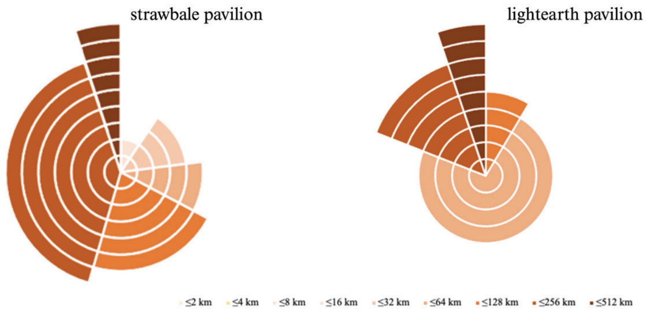

Figure 1. Concentric charts showing transport distances from suppliers to the construction site, along with the corresponding material quantities by weight for each pavilion.

For the strawbale pavilion, most materials – 40% by weight – were sourced from 64-128 km, primarily comprising timber, stones, and rice straw. An additional 22% of the total material weight came from a 32-64 km range, largely consisting of wheat straw. Only 5% was procured from beyond 128 km, representing approximately 1.7 tonnes of building materials.

In the case of the light earth pavilion, 72% of the materials by weight were sourced within a 16-32 km radius. This is predominantly due to clay and recycled aggregate, both high-density materials obtained from locations 23 and 17 km away, respectively. A further 14% of the material weight was supplied from within a 64-128 km range, most of which consists of timber. Only 5% of the material originated from greater distances, corresponding to approximately 4.5 tonnes of material – largely reed insulation panels. Although suppliers for reed panels were identified at shorter distances from the site, in these cases the panels were imported. The selected supplier both manufactures the panels and sources the raw materials near their production facility.

All suppliers are based in Italy except for the waterproofing membranes used in the strawbale pavilion. Most suppliers (15 of 21) are located in Piedmont, covering about 95% of the material weight for each pavilion. Materials were mostly bought directly from manufacturers; only six acted as distributors, supplying 21% of the strawbale and 2% of the light earth pavilion's materials – reflecting the simplicity of the construction materials used.

3.2. Raw material sources. Correlation between raw materials origin and environmental impact

The source of raw materials was correlated with the weight portion of each material in the buildings and their respective impact. The Life Cycle Assessment (LCA) of the pavilions has been previously published [23]. The impact category considered in this case is Global Warming Potential ($GWP_{100a,ICPP2021}$) values for stages A1-A3, excluding the contribution of biogenic carbon.

From the analysis presented in Figure 2 and Figure 3 it becomes clear that for most of materials in terms of weight, it is possible to trace back the raw material sources with an acceptable degree of certainty. In fact, only 0,46% and 0,20% of the material weight respectively, results of unknown or mixed origin. These are materials of high impact, and, despite the small quantities in which they are used, make up for approximately 22 and 16% of the overall impacts. Approximately 47% of the raw materials in the strawbale pavilion, are sourced from within 128 km from the construction site. In the case of the light earth pavilion, this portion is much higher – around 83% – mostly due to the large amount of clay and recycled aggregate. In both cases, the materials sourced in proximity present lower impacts compared to the rest, 31 and 18% respectively for the 0-128 km range.

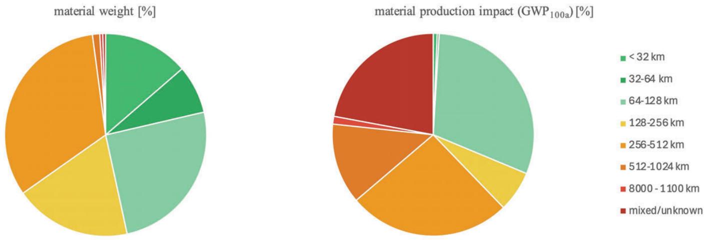

Figure 2. Sources of raw materials for the strawbale pavilion categorised into kilometric radius from the construction site divided by material weight (left) and material impact (right).

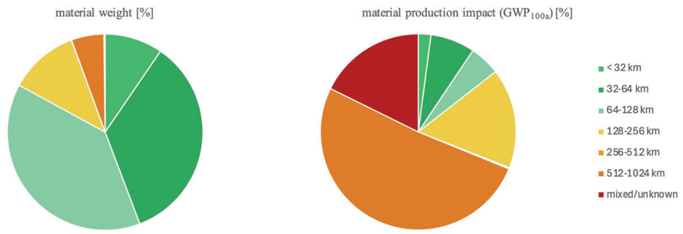

Figure 3. Sources of raw materials for the light earth pavilion categorised into kilometric radius from the construction site divided by material weight (left) and material impact (right).

4. Where did the money go? Economic flows from the construction project to the final recipients

4.1. Analysis of project costs

The actual costs for both pavilions, divided by the defined categories, are presented in Figure 4. The material costs are the largest contributors in both cases, followed by labour costs. In fact, the later make for approximately 35 and 32% of the cost for the strawbale and the light earth pavilion respectively, even though the construction process relies on training workshops during which a significant part of the activities are carried out by students. This indicates that the construction is labour-intensive, and that specialised craftsmanship is required for a significant part of the works. In a conventional site, where activities are carried out by specialised workers, this contribution would have probably been higher.

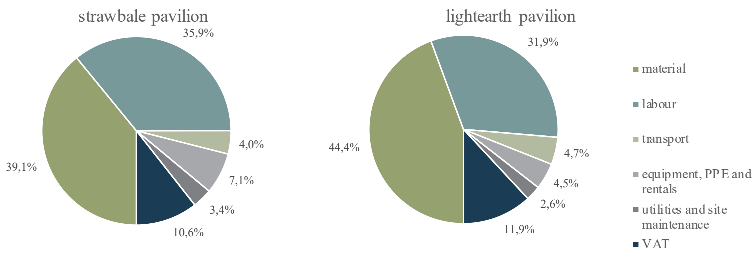

Figure 4. Actual costs partition in main categories for both pavilions.

However, it should be mentioned that the cost of materials is underestimated, considering a part of it was sponsored by companies. The sponsored materials were estimated separately based on market prices. VAT costs on sponsored material are not calculated. An overview of the cost partition including the estimation for sponsored material is presented in Figure 5. The materials costs rise to approximately 52%, and the labour costs are approximately 28%, which is still a relevant portion of the overall costs.

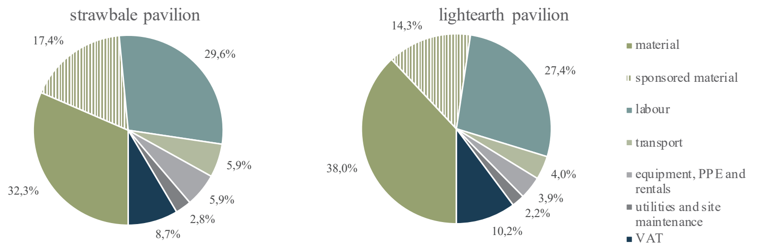

Figure 5. Costs partition including the estimation of sponsored material.

4.*2. Analysis of economic flows*

The economic flows are represented following the approach recommended by previous studies by Ioannidou and colleagues, in turn adopted from the tiered approach of the supply chain management [18,19].

The tiered approach is adapted for the specific case studies, with each tier representing a different level of analysis: project, local, national, and European. At the project level, all costs are categorized and then assigned to one of three geographical tiers: local (Piedmont Region), national (rest of Italy), and European (EU and Switzerland, excluding Italy).

Material costs are assigned fully to the supplier's tier, with no breakdown beyond the manufacturer due to lack of data on financial flows. If supplier and manufacturer are in different tiers, 25% of the cost is assigned to the supplier. The analysis ends at the manufacturer; raw material origins are not considered. VAT and utility costs are allocated to the national tier. Transport costs follow the supplier's location. Labour, rentals, site maintenance, and waste disposal are assigned to the local tier based on contractor location. Equipment and PPE costs are split: 25% to the local tier, reflecting supplier location, and the remainder to higher tiers.

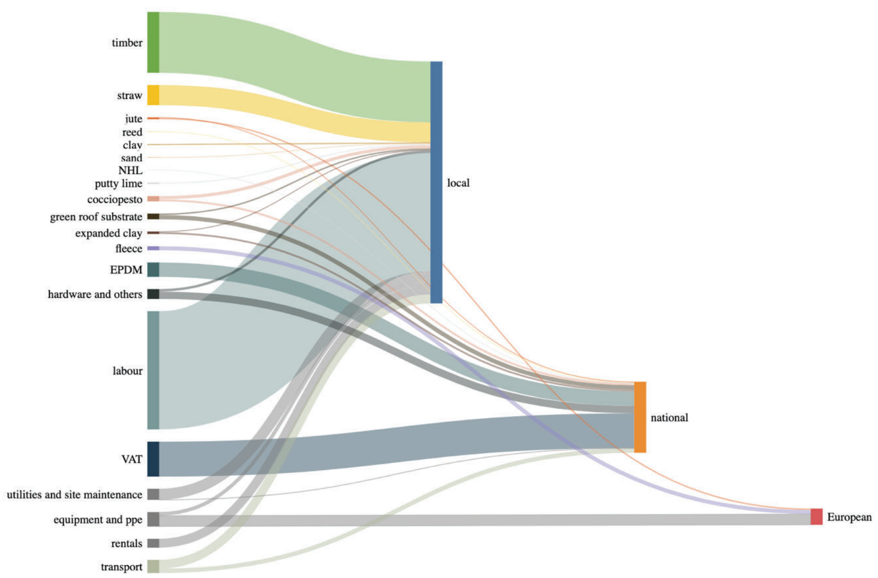

Figure 6. Economic flow diagram for the construction of the strawbale pavilion.

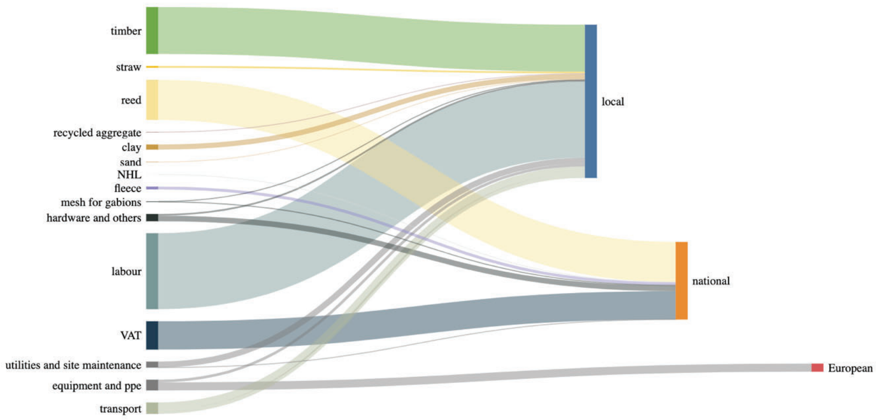

Figure 7. Economic flow diagram for the construction of the light earth pavilion.

According to the analysis presented in Figure 6 and Figure 7, most of the final recipients are located within the Piedmont Region, approximately 73% for the strawbale pavilion and 63% for the light earth pavilion. This result is a direct influence of the labour-intensive construction process and of the choice of materials. An important portion of the costs are located on a national level outside the region, respectively 22% and 34%. This is to a large extend due to VAT costs, which would remain unchanged regardless of the choice of materials. However, this category is also influenced by some of the materials, more significantly from the EPDM in the case of the strawbale pavilion and the reed panels in the case of the light earth pavilion. Costs outside the national boarders account for only 5 and 3% of the overall costs.

To better understand the geographical distribution of the economic flows from a distance perspective, the analysis is performed by classifying the suppliers and manufacturing in the kilometric ranges. This analysis is performed only on the material costs since these are not only a substantial part of the overall costs, but also depend to a large extend from design choices. Furthermore, it would be difficult to classify in a kilometric range most of the other cost.

The materials cost flow analysis for the strawbale pavilion is presented in Figure 8. Most of the recipients are in a 64-128 km ratio from the site, which is coherent with the material weight distribution. However, costs allocated in a 0-64 km range have less impact on the overall costs compared to those located beyond 128 km. The opposite is true in terms of material weight.

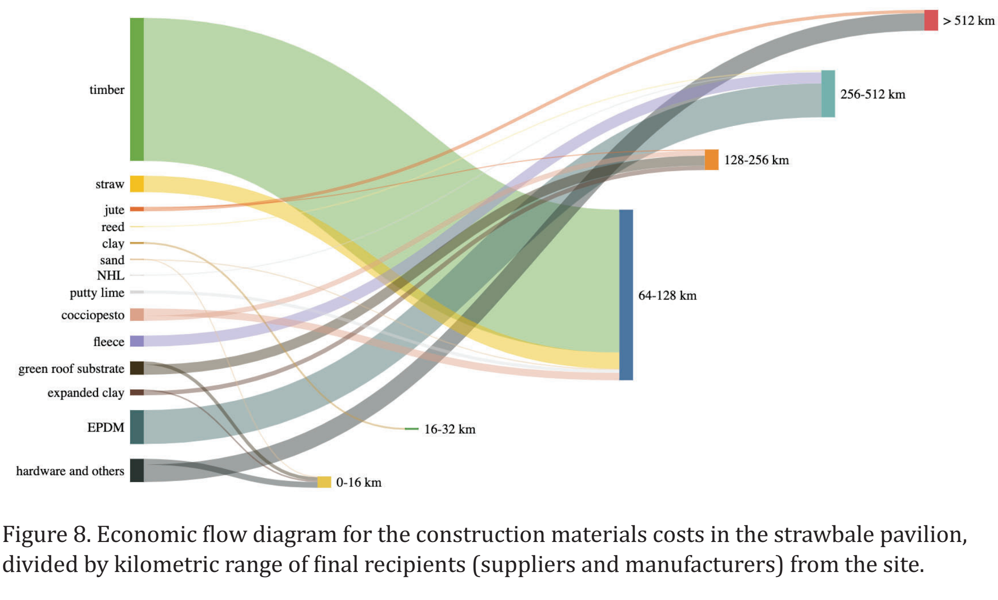

Figure 8. Economic flow diagram for the construction materials costs in the strawbale pavilion, divided by kilometric range of final recipients (suppliers and manufacturers) from the site.

For the light earth pavilion (Figure 9), most recipients are within 64–128 km of the site, followed by those 256–512 km away. In contrast, most materials by weight came from within 16–32 km, with only 5% sourced from beyond 128 km. This highlights that sourcing heavy materials locally doesn't guarantee most spending stays nearby, as these materials are often low-cost despite their volume.

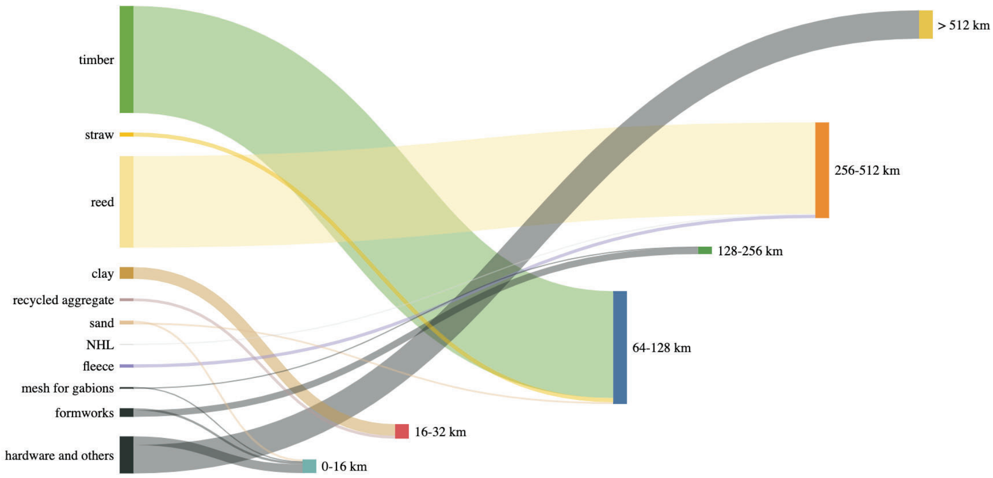

Figure 9. Economic flow diagram for the construction materials costs in the light earth pavilion, divided by kilometric range of final recipients (suppliers and manufacturers) from the site.

5. Conclusions

In this paper the materials origins and the economic flows of the construction process were assessed for two research pavilions. The construction focuses on the application of regenerative building techniques and the use of local bio-based and low carbon geo-based materials to the largest extend possible.

The analysis reveals that bio-based, minimally processed materials – comprising most of the building mass – are easier to trace, while high-impact products often have mixed or unknown origins. Though used in small quantities, their environmental and financial impacts remain limited.

Sourcing materials near the site doesn't always mean local financial flows, especially if raw materials come from elsewhere. Material origin and financial flows don't always align: while many costs stay local, some high-cost items represent a small share by weight.

Simpler materials are easier to trace in terms of composition, origin, and financial flow. This also applies, to some extent, to recycled materials and even more to reused components, though the latter weren't used in this study.

Limitations of the analysis include data availability from suppliers and assumptions about raw material origins. The project's educational setting also lowered labour costs, affecting comparability with typical market conditions.

In principle, construction should prioritise local, low-impact materials with traceable origins, benefiting both the environment and local economies. However, sourcing materials nearby doesn't guarantee that most investment stays local, as high costs often relate to lightweight components. Furthermore, quantifying the impact the final recipients have on local community development would require in-depth financial analyses and larger datasets. While fully assessing local impact requires detailed financial data, the proposed analysis helps identify supply chain gaps and supports informed decisions favouring localised construction.

Further research and a broader range of diverse case studies are needed to address the initial questions surrounding the definition of 'localness' in construction. This study offers a methodological approach to quantifying the theoretical criteria underlying the concept and, in doing so, exposes the challenges and complexities of applying it in real-world contexts.

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