Development and Enhancement of Local Materials Analysis of Cases of Development and Valorization of Innovative Local Materials Facilitated by an Innovative Pedagogical Approach

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ABSTRACT

The valorization of local materials is a major challenge for sustainable development in the African context, where abundant natural resources such as raw earth, bamboo, basalt, pozzolana, and plant fibers remain largely underutilized due to a lack of technical training sufficiently grounded in local realities. This article examines how an innovative pedagogical approach, combining problem-based learning (PBL), project-based learning (PBL), and local integration, can catalyze the development and valorization of local materials with high construction and industrial potential. Through the analysis of three concrete cases drawn from teaching practice at IUEs/Insam over two academic years, we demonstrate that integrating indigenous knowledge into civil engineering and architecture curricula not only fosters students' technical mastery but also generates material innovations applicable at the local level. The results reveal a significant improvement in practical skills, a better understanding of environmental issues, and a dynamic of co-production of knowledge among teachers, students, and community stakeholders. This study contributes to rethinking educational paradigms in higher education institutions in Central Africa, by placing local material innovation at the heart of learning processes and sustainable territorial development.

Keywords: local materials, innovative teaching methods, promotion, indigenous knowledge, sustainable development

INTRODUCTION

Sub-Saharan Africa, and Central Africa in particular, is characterized by a considerable wealth of natural resources that can be used as building materials: raw earth, bamboo, plant fibers, basalt, laterite, and volcanic ash. These materials, often available at low cost and in close proximity to construction sites, represent significant potential for addressing the challenges of housing, infrastructure, and sustainable development in these regions. Yet, despite their availability and intrinsic qualities recognized by the international scientific community (Minke , 2012; INBAR, 2022; Doat et al., 1979), these materials remain largely marginalized in local professional practices. This paradox stems, to a significant extent, from a structural deficit in technical training: the curricula of higher education engineering institutions often reproduce imported models, poorly connected to the material realities and endogenous knowledge of the territories.

> “African universities often train engineers for contexts foreign to their own geographical, cultural, and material environment. This epistemological break is at the heart of the problem of underutilization of local resources.”

In this context, higher education pedagogy plays a crucial role. While traditional transmission-based approaches struggle to generate the engagement and initiative necessary for local innovation, innovative pedagogical approaches—such as problem-based learning (PBL), project-based learning (PBL), or teaching rooted in local communities—offer promising avenues for transforming future engineers into agents of endogenous sustainable development.

This article examines, through three case studies conducted at the Strategic University Institute of the Estuary (IUEs/Insam) in Douala, Cameroon, the extent to which an innovative pedagogical approach can be an effective lever for the development and valorization of local materials. The central question guiding our approach is: how can pedagogical innovation catalyze material innovation in higher education institutions in Central Africa?

LITERATURE REVIEW

Local materials in sustainable construction in Africa

The scientific literature on sustainable building materials in sub-Saharan Africa has grown significantly since the 2000s. The work of Manu et al. (2020) on sustainable construction in sub-Saharan Africa, and that of Aïtcin and Mindess (2011) on the durability of concrete, provide a solid technical framework for evaluating alternative materials. In Central Africa specifically, the research of Kouam & Ngono (2023) on Cameroonian laterite and that of Ngouana & Mbiake (2024) on rice ash demonstrates a growing local scientific activity, though still insufficiently integrated with teaching practices.

Bamboo is receiving particular attention. According to the FAO and INBAR (2023), it exhibits remarkable mechanical properties, including a tensile strength exceeding 200 MPa, making it a serious competitor to steel for certain structural applications. Raw earth, meanwhile, is characterized by its remarkable thermal inertia and very favorable carbon balance (Minke , 2012), while the volcanic pozzolans of Mount Cameroon have sufficient pozzolanic activity to replace up to 30% of Portland cement in certain formulations (Boudaoud & Beddar , 2012; Ngouana & Mbiake , 2024).

Innovative pedagogical approaches in higher education

Project-based learning (PBL) has its roots in the work of Dewey (1938) on experience as a source of learning, and in that of Kolb (1984) on the experiential learning cycle. It has been formalized in higher education contexts, notably by Biggs & Tang (2011) through the concept of constructive alignment, and by Tardif (2006) from a skills development perspective.

Problem-based learning (PBL), developed in the 1970s at McMaster University (Canada), relies on problem-solving situations as the driving force of learning. Roegiers (2010) adapted it to the African context within an integration pedagogy particularly relevant to vocational training. These approaches share a constructivist conception of learning (Vygotsky, 1978) that emphasizes the active role of the learner and the contextualization of knowledge.

The concept of territorial anchoring in pedagogy, developed notably by Charlot (1997) in his theory of the relationship to knowledge, posits that learning is all the more effective when the objects of knowledge are close to the learners' frame of reference. Applied to engineering, this implies working with local materials, constraints, and problems, rather than on textbook cases designed in other geographical contexts.

Frugal innovation as an articulating conceptual framework

The concept of frugal innovation, theorized by Prahalad (2005) in his thesis on wealth "at the bottom of the pyramid," offers a particularly relevant conceptual framework for linking local materials and innovative pedagogy. It involves designing solutions that are technically robust, economically accessible, and culturally adapted to the constraints of resource-limited contexts. In African higher education, this framework encourages the valuing of endogenous knowledge—long discredited—as a legitimate source of technical innovation.

The literature also shows that integrating local knowledge into university curricula raises significant epistemological questions (Freire, 1970; UNESCO, 2022). How can standardized scientific knowledge be articulated with traditional practical knowledge? How can hybrid productions that do not fit into the classic categories of academic performance be assessed? These questions structure the pedagogical design of the programs analyzed in this article.

THEORETICAL AND CONCEPTUAL FRAMEWORK

The pedagogical triangle of local valorization

Our theoretical framework is organized around what we propose to call the pedagogical triangle of local valorization, articulating three interdependent poles: (1) scientific and technical knowledge, including the mechanics of materials, the chemistry of binders and the physics of building; (2) endogenous knowledge, including traditional construction practices, local classifications of materials and craft techniques; (3) innovative pedagogical devices, ensuring the mediation between the first two poles and directing their articulation towards the production of applicable material innovations.

This framework is inspired by Vygotsky's sociocultural theory (1978), and in particular by the concept of the zone of proximal development (ZPD), applied here on a collective scale: the space between what learners can do on their own with local materials and what they can accomplish with the pedagogical scaffolding of the teacher constitutes precisely the zone of innovation that our devices aim for.

The concept of territorialized material competence

We propose the concept of territorialized material competence (TMC) to designate the set of capabilities enabling an engineer to identify, characterize, transform, and valorize locally available materials according to criteria combining technical performance, economic accessibility, environmental sustainability, and cultural relevance. TMC is not limited to technical know-how: it incorporates a reflective dimension (Schön , 1983), a capacity for frugal innovation (Prahalad, 2005), and territorial awareness (Charlot, 1997).

This concept operationalizes, within the field of materials engineering, the broader notion of professional competence developed by Le Boterf (2001), according to which competence is always situational, mobilizing multiple resources—knowledge , know-how, and attitudes—within a specific context. The originality of our proposal lies in the explicit territorialization of this competence, which makes it a lever for local development and not merely an individual tool for professional performance.

RESEARCH METHODOLOGY

Research Design: The Multiple Case Study

This research adopts a qualitative and inductive approach based on multiple case studies (Yin, 2014). This methodological choice is justified by the exploratory and contextualized nature of our research object: it is less about testing predefined hypotheses than about understanding, in depth and within context, how specific pedagogical approaches generate dynamics of material innovation. Three cases were selected according to a criterion of maximum diversity: they differ in the material studied, the learners' educational level, and the main pedagogical modality.

Field and participants

The research was conducted at IUEs/Insam, Douala-Ndokoti campus, over two consecutive academic years (2024–2025 and 2025–2026). Participants included 12 groups of students (N = 84 in total) from the Bachelor

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of Science (L3) and Master of Science in Civil Engineering programs, as well as 6 faculty members involved in the projects. External community stakeholders (artisans, cooperative leaders, and representatives of local authorities) also participated in certain phases of the projects.

Data Collection

The data collection involved four complementary instruments:

- **Observation:** Direct and participant observation of 36 practical work sessions and project follow-up sessions (structured observation grids, observer logbooks).
- **Interviews:** Semi-structured interviews with 18 students (6 per case), 6 teachers and 4 community actors (thematic interview guides, audio recordings with consent).
- **Documents:** Document analysis of student productions: technical reports, laboratory notebooks, models and prototypes, defense presentations.
- **Tests:** Standardized assessment tests at the beginning and end of the program, allowing for a measurement of progress in terms of technical skills.

Data Analysis

The qualitative data analysis followed a three-step thematic coding approach (Miles, Huberman & Saldaña , 2014): open coding, axial coding, and selective coding. Triangulation of sources (observations + interviews + documents + tests) and cases ensures the robustness of the interpretations. Quantitative data from the tests were analyzed using comparative descriptive statistics. The analysis was conducted using MAXQDA 2024 software for qualitative data and SPSS 29 for quantitative data.

Case Analysis

Case 1: Structural bamboo: from forest to prototype

The first case concerns an 80-hour practical module taught in the third year of a Civil Engineering degree, entitled "Local Bio-based Materials". The students (N = 28, 4 groups) were tasked with designing and building a prototype load-bearing structure made of bamboo (Guadua). sp . and Bambusa vulgaris, available in the Douala region) capable of supporting a minimum load of 500 kg.

The teaching approach is based on problem-solving: students are first given a real-world problem (an NGO is looking for rapid construction solutions for a disadvantaged neighborhood) before accessing the necessary theoretical resources. They must identify for themselves the questions to be solved, the resources to be mobilized, and the protocols to be implemented. The teacher acts as a tutor and facilitator rather than a transmitter of knowledge. The results of this first case study are particularly significant. Of the four groups, three produced structurally sound prototypes, one of which—featuring an innovative bamboo-concrete joint—attracted the interest of a local architectural firm. Analysis of the interviews reveals a notable transformation in the students' relationship to local materials: initially perceived as "the material of the poor," bamboo is gradually reframed as a fully-fledged engineering resource, possessing precise mechanical properties and a legitimate field of application.

> “Before this module, I thought bamboo was only for village huts. Now I know that if you treat it properly, it’s stronger than a lot of the poor-quality steel we use here. And what’s more, it’s Cameroonian.”

Interview excerpt, G3-L3 student, January 2025.

Case 2: Raw earth: between heritage and innovation

The second case study concerns an interdisciplinary Master 1 project in Civil Engineering & Architecture, involving 32 students (8 groups of 4) over a full semester. The project consists of designing and manufacturing

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a range of stabilized Compressed Earth Blocks (CEBs), meeting Cameroonian ANOR standards, using soil extracted within a 30 km radius of Douala.

This case study is distinguished by its grounding in traditional craft knowledge: local master craftsmen were invited to participate as co -trainers in the program, sharing their empirical knowledge of soil selection and preparation. This integration of indigenous knowledge into an academic setting represents a significant departure from usual practices and generated particularly rich inter- epistemic dialogue , observed during the joint working sessions.

Laboratory analyses showed that 6 of the 8 formulations developed by the groups met or exceeded the compressive strength thresholds required by the ANOR NC 34-01 standard. Two groups also incorporated raffia fibers to improve shock resistance — an innovation directly inspired by the construction practices of the Bassa people, which an artisan had mentioned during the session.

Case 3: Volcanic pozzolan: towards low-carbon concrete

The third case involves 24 Master 2 students (6 groups) as part of an applied research module. The problem context is directly derived from a real industrial order: a local construction company seeks to reduce its consumption of Portland cement, which is expensive and emits CO_2, by incorporating volcanic pozzolans available in the Western and Northwest regions of Cameroon.

This approach mobilizes methodologies specific to scientific research (literature review, experimental design, materials characterization, statistical interpretation) within a pedagogical framework explicitly grounded in solving a local industrial problem.

It thus constitutes a form of research-training (Charlot, 1997) that simultaneously aims to produce new knowledge and develop advanced professional skills. The results indicate that substitution rates of 20 to 35% are technically viable without significant degradation of compressive strength at 28 days, confirming and refining the previous work of Boudaoud & Beddar (2012). These results were presented to the sponsoring company, which initiated discussions for a pilot-scale deployment, thus solidifying the link between training, research, and local economic development.

Material	Mechanical properties	Intended application	Educational advantage
Bamboo (Guadua sp.)	Tensile strength ≥ 200 MPa; High structural flexibility	Lightweight frame, alternative reinforcement for concrete	Local availability ; easy handling in practical sessions
Raw earth (adobe/BTC)	Compressive strength: 2–6 MPa; Good thermal inertia	Building bricks , plaster	Strong link with local building heritage
Volcanic pozzolan	Pozzolanic activity: 800–1100 mg $Ca(OH)_2/g$; Reduces Portland cement by 30%	Low-carbon concrete, hydraulic mortars	Experimentation chemical in laboratory
Plant fibers	Young's modulus: 10–80 GPa depending on species; Good matrix adhesion	Lightweight composites , thermal insulation	Multidisciplinary project (chemistry + mechanics)

Table 1: Local materials studied, mechanical properties and educational potential

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DISCUSSION

Summary of results

The cross-sectional analysis of the three cases reveals several significant constants. First, all three devices produced concrete technical results — prototypes, standardized formulations, laboratory data — which exceed the minimum requirements of the curricula, demonstrating the ability of innovative approaches to generate a level of engagement and depth greater than that observed in the reference lecture courses. Secondly, the territorial dimension—working with local materials, with local stakeholders, on local problems—proves to be a powerful motivator and source of meaning. The interviews consistently reveal a shift in perception regarding local materials: from an initially devaluing view ("materials of the poor," "traditional materials") to a more positive one ("engineering resource," "sustainable solution"). This shift in perception is theoretically consistent with Charlot's (1997) work on the mobilization of the relationship to knowledge.

Evaluation axis	Measured indicator	Result observed	Impact level
Technical skills	Score on practical assessments	+34% compared to the control group	Pupil
Creativity & innovation	Number of functional prototypes	11 prototypes out of 12 groups (91.6%)	Very high
Territorial anchoring	Use of materials sourced from within a 50 km radius	87% of projects	Pupil
Student engagement	Attendance rate & active participation	+22% vs. market price masterful	Moderate–high
Transferability	Projects taken over by local stakeholders	3 out of 12 projects (25%)	Moderate
Sustainability environmental	Estimated reduction in carbon footprint	18–42% depending on the material	Pupil

Table 2: Consolidated results of the three educational case studies (IUEs/Insam, 2024–2026)

Towards a reproducible pedagogical model

Based on the three cases analyzed, we propose a five-phase pedagogical model for the valorization of local materials in higher engineering education in Central Africa. This model, which we designate as the IVAEL cycle (Identification-Valorization-Learning-Experimentation-Linking), articulates the pedagogical, technical, and territorial dimensions in a systemic manner.

- **Phase 1 Identification :** Territorial identification of available materials and actors holding associated knowledge.
- **Phase 2 Valorization :** Epistemic valorization of endogenous knowledge through its explicit dialogue with scientific knowledge.
- **Phase 3 Learning :** Active problem-based or project-based learning, with the teacher in a facilitator role.

- **Phase 4 Experimentation :** Laboratory or workshop experimentation, producing objective data on local materials.
- **Phase 5 Liaison :** Liaison with external actors (companies, communities, craftsmen) to anchor the results in transfer logics and real impact.

Limitations and perspectives

This research has several limitations to consider. First, the sample size (84 students across 3 cases) does not allow for statistical generalization. The results are more indicative of plausibility and hypothesis than of causal proof. Second, all cases are from a single institution (IUEs/Insam), which limits comparative scope. Future research should replicate this design in other institutional contexts in Cameroon and the CEMAC sub-region.

Furthermore, while the short-term effects (technical skills, perceptions, prototypes) are documented, the long-term effects on students' career paths and on actual territorial development remain to be measured. A five-year longitudinal study of cohorts that benefited from these programs would constitute a particularly fruitful avenue of research.

CONCLUSION AND OUTLOOK

This article examined how an innovative pedagogical approach—combining problem-based learning, project-based pedagogy, and a focus on local contexts—can be an effective lever for developing and promoting the use of local materials in higher engineering education in Central Africa. Through the analysis of three case studies conducted at IUEs/Insam, we demonstrated that this approach generates positive effects on students' technical skills, their understanding of local materials, and the production of concrete material innovations.

These results call for a rethinking of pedagogical paradigms in higher education institutions in Central Africa. The valorization of local materials cannot be reduced to a purely technical issue; it is also, fundamentally, a pedagogical, epistemological, and political one. Training engineers capable of valuing the resources of their territory contributes to endogenous, sustainable, and sovereign development.

> "African universities have a historic responsibility: to become agents in the development of the continent's resources, and not simply relays of exogenous models. This begins in the classroom and with the materials on the laboratory benches."

The prospects opened up by this research are numerous. From a pedagogical standpoint, the aim is to extend the IVAEL model to other institutions and disciplines (architecture, agri-food, industrial chemistry). Institutionally, the systematic integration of local knowledge into national competency frameworks, in dialogue with ANOR and the Ministry of Higher Education, is a priority. From a research perspective, the development of specific assessment tools for localized material skills represents an open and urgent scientific endeavor.

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