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ICBBM 2025 in Rio de Janeiro: A synthesis of recent advances, current gaps and emerging directions in bio-based building materials

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Abstract

The 6th International Conference on Bio-Based Building Materials (ICBBM 2025) met in Rio de Janeiro from 17 to 20 June 2025, the first edition held outside Europe. Its proceedings (RILEM Bookseries Vols. 60–61, Springer) bring together 144 contributions: 136 peer-reviewed papers across eleven thematic sessions, plus eight keynote and invited lectures. That is roughly twice the size of recent editions. This Technical Letter reads the corpus rather than cataloguing it. We find a field that is uneven by session: a handful of topics already rest on shared methods and emerging standards, several are growing fast but remain methodologically loose, and a few, mycelium and biochar in particular, have only recently emerged as separate topics. Cutting across the sessions, the same weaknesses appear: durability is measured in various ways, life-cycle results for nominally identical walls differ by an order of magnitude, biological variability is rarely carried through to design values, and building-scale evidence is thin. We group these into nine structural gaps and three deployment barriers the literature has mostly left to others: cost, supply chain, and the financing of demonstrators. The closing argument is that the corpus already contains what it needs to reframe bio-based construction from "low-carbon" to "carbon-storing": material-scale sequestration, life-cycle permanence anchored in durability data, end-of-life scenarios that separate delay from storage, and certification frameworks that would have to recognise that permanence. The 1788 pages produced in Rio describe a field moving from demonstration toward early deployment, while still lacking robust building-scale evidence. The next step is to align materials science with the environmental-engineering, regulatory and industrial-economic communities it has so far engaged only loosely.

Keywords: Bio-based building materials; Bio-aggregates; Hempcrete; Earth construction; Natural fibres; Mycelium; Life-cycle assessment; Biogenic carbon storage; Durability; 3D printing; RILEM; ICBBM 2025.

1 Background

Bio-based construction is, in one sense, the oldest way of building: earth, timber, bamboo, straw and plant fibres have housed people on every continent for millennia. What is recent is the effort to put that practice on a quantitative, reproducible footing, and for two decades much of that formalisation happened in a small set of mostly European laboratories. The International Conference on Bio-Based Building Materials grew out of that effort (Clermont-Ferrand 2015 and 2017, Belfast 2019, Barcelona 2021, Vienna 2023) before moving to Rio de Janeiro from 17 to 20 June 2025 for its sixth edition, hosted by the Federal University of Rio de Janeiro (UFRJ/COPPE). The change of venue matters: it gave access to the agro-industrial streams, vernacular techniques and climates the European programme had largely theorised about rather than worked with directly.

The Rio proceedings gather 144 contributions: 136 peer-reviewed papers across eleven thematic sessions, plus eight keynote and invited lectures. They were selected by an international committee of more than fifty members from twenty countries, amounting to roughly twice the body of work of previous editions. The sessions span the whole chain of bio-based construction, from raw resource to building function, and this Letter reads across them. We are deliberately editorial: we flag where a topic is mature and where its claims run ahead of the evidence, pull out the trends that cut across sessions, name the gaps the corpus makes visible, and set out where the field is heading. The central argument developed throughout this Letter is that bio-based

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construction is best understood not as a low-carbon alternative but as a way of storing carbon in the built environment, provided that durability, life-cycle permanence and end-of-life scenarios are properly accounted for.

2 The conference at a glance

Figure 1 shows how the 136 thematic papers divide across the eleven sessions, and the distribution is itself informative: natural-fibre reinforcement, mechanical characterisation and innovative bio-binders dominate, while environmental assessment, with five papers, is the smallest session by some margin, an imbalance we return to in Section 5. Behind the headline of a more global conference lies a distinction worth keeping in view. Some of the new work applies established, largely European protocols to locally available resources, the R3 and strength-activity testing of sugarcane-bagasse and corn-straw ashes is a clear case [Siqueira et al.; Gonçalves Júnior et al.], where the open question is portability. Other work pushes harder, questioning the performance assumptions built into those protocols on climatic, material or socio-technical grounds: mycelium blocks designed for the Brazilian climate [Pires Teixeira et al.], engineered-wood housing for the tropics [Xavier & Caldas], a Latin-American re-reading of the self-healing literature, the urban-heat-island programme [Hijazi et al.]. The first broadens the evidence base; the second matters more, because over the coming decade it will force design rules to be re-derived rather than translated. The four keynotes, Coussot on moisture transport, Zea on bamboo and standardisation, Cordeiro on biomass-derived pozzolans, Srubar on living materials, shared a single concern beneath their different subjects: the distance still separating laboratory evidence from the durability, standards and deployment that real buildings demand.

3 Eleven thematic threads: an editorial reading

The eleven sessions are at very different stages of maturity. Table 1 sets this out session by session, with maturity stage, dominant internal tension, and the papers that best illustrate each. Three patterns stand out: the sessions are not at the same level of development, the corpus contains real internal contradictions as well as points of agreement, and some difficulties recur across almost every session.

The sessions are not at the same level of development. Mechanical and physical characterisation (3.5) is the most settled: drying and shrinkage of flax- and wood-based concretes are now measured comparably from one laboratory to the next, largely because the community has converged on the RILEM TC 236-BBM and TC 107-CSP protocols. The self-healing strand of the durability session (3.8) is similarly mature, having moved past proof-of-concept to engineering questions of capsule design and delivery. A larger middle group is clearly on the rise but still methodologically loose: bio-binders and additives (3.2), cementitious composites from agricultural ashes (3.4), natural-fibre reinforcement (3.3), additive manufacturing (3.1), earth-based construction (3.10) and the hygrothermal session (3.11) all show real progress alongside protocols that vary too much between papers to support clean comparison. Modelling (3.9) is younger still, with a first machine-learning model appearing in the corpus. And two material families, mycelium and biochar, reach session-defining scale for the first time, appearing as separate topics rather than as curiosities attached to the binder or durability work.

Where the corpus agrees, it agrees on the value of bio-based solutions and on the methods now shared for characterising them; where it contradicts itself, the contradictions are revealing rather than trivial. The clearest one runs through fibre durability: papers using ordinary Portland cement report fibre degradation within months, driven by portlandite-induced mineralisation and alkaline hydrolysis of hemicellulose and lignin, while papers using LC3 (lower free-lime content), geopolymer binders (different pore-solution chemistry despite comparable or higher pH) or coated fibres report markedly longer service life. Durability therefore depends on the specific hydration chemistry of the binder, not simply on its pH, a distinction rarely made explicit in the corpus. A second contradiction runs through the ash work, where the substitution rate of cement reported as optimal swings from 10 % to 40 % for similar agricultural ashes, because water-to-binder ratio, workability target and curing are seldom held constant from one study to the next. A third, sharpest of all, sits in life-cycle assessment, where studies of nominally identical hempcrete walls disagree by an order of magnitude.

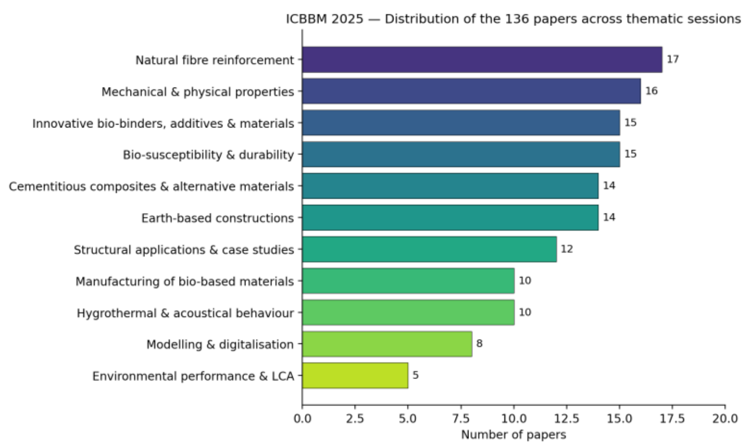

Figure 1. Distribution of the 136 ICBBM 2025 papers across the eleven thematic sessions of the proceedings.

Table 1. Editorial reading of the eleven thematic sessions of ICBBM 2025: paper count, maturity stage, dominant internal tension, and representative papers.

Session	Papers	Maturity stage	Dominant tension or contradiction	Representative papers
3.1 Manufacturing of bio-based materials	10	Engineering optimisation (3D printing); systematic characterisation	Component- and wall-scale demonstration mostly stated rather than shown	Tinoco et al.; Sahoo & Gupta; Inga Guillen et al.; Sonebi et al.
3.2 Innovative bio-binders, additives and materials	15	Heterogeneous; systematic characterisation for mycelium and bio-PU	Bio-rheology cluster: same admixtures simultaneously claimed as retarders, hydration controllers and viscosity modifiers, with non-comparable dosage protocols	Pires Teixeira et al.; Ortega Exposito et al.; Wilson & Calabria-Holley; Caruso et al.
3.3 Natural-fibre reinforcement	17	Systematic characterisation; isolated entries into engineering optimisation	Binder-dependent durability framed silently as a material property (alkaline degradation in OPC vs claimed stability in LC3 / geopolymer / coated systems)	flax-TRM and natural-FRP retrofit; self-healing and bamboo-connection reviews
3.4 Cementitious composites and alternative-material valorisation	14	Systematic characterisation	"Optimal" cement-substitution rate varies 10–40 % across nominally similar agricultural ashes, without constant w/b or constant workability benchmarks	Siqueira et al.; Gonçalves Júnior et al.; Abu Askar et al.; Sadrolodabaee et al.; Rashid et al.
3.5 Mechanical and physical properties	16	Systematic characterisation; strong methodological convergence on RILEM TC 236-BBM and TC 107-CSP	Specimen population dominated by 40×40×160 mm prisms and Ø110×220 mm cylinders; element- and wall-scale tests rare; batch variability not propagated to characteristic design values	Gufflet et al.
3.6 Bio-based structural applications and case studies	12	Case-by-case engineering	Holistic ambition (system-level performance) vs predominantly component-scale evidence; full-building life-cycle data scarce	Xavier & Caldas; Hijazi et al.; Koster
3.7 Environmental performance and LCA	5	Methodologically unstable	Order-of-magnitude divergence between studies on nominally identical assemblies; persistent disagreement on functional units, biogenic-carbon convention, end-of-life and land-use change	Santana & Ouellet-Plamondon
3.8 Bio-susceptibility and durability	15	Engineering optimisation in self-healing; early systematic characterisation in plant-fibre durability	Multi-year field data scarce; biodegradation often qualitative; novel binder–plant-particle compatibility test not yet RILEM-standardised	Delhomme et al.
3.9 Modelling and digitalisation	8	Characterisation; first tentative entry into machine learning	Almost no model validated against multi-year on-site data; hygrothermal hysteresis rarely embedded	Tedjditi & Kaouane
3.10 Earth-based constructions and building materials	14	Systematic characterisation; deployment-ready elements where vernacular service-life evidence exists	Two evidence regimes (engineered vs vernacular) with different performance vocabularies; reconciliation itself a research direction	Riffi et al.; Paris earthen-structure and cob case studies
3.11 Hygrothermal and acoustic behaviour	10	Systematic characterisation; one in-situ deployment	On-site multi-year monitoring still the exception; hysteresis–in-situ validation gap	Achour et al.; Mutel et al.

Some difficulties recur in almost every session. Long-term, multi-year field data are scarce nearly everywhere; on-site validation is the exception rather than the rule, the straw-wall monitoring of Achour et al. being one of the few; and the population of test specimens is still dominated by 40×40×160 mm prisms and Ø110×220 mm cylinders, with element- and wall-scale evidence rare and batch variability seldom carried through to characteristic design values. These limitations are the subject of the gap analysis in Section 5.

4 Cross-cutting trends

Read sideways rather than session by session, the corpus shows half a dozen movements no single session captures on its own.

The first is simply that the palette of bio-resources has widened. Hemp is still the most-cited material (Fig. 3), but it now shares the stage with rice husk, sugarcane bagasse, vine shoots, miscanthus, banana, coconut, olive and coffee husk, mycelium, algae, biochar and lignin. This is the diversification the change of venue made almost inevitable: each region brought its own by-products, and the field has drifted from a short list of canonical aggregates towards a palette that depends on where you are building.

Earth construction is another prominent topic in this corpus. The earth session is one of the larger ones, and it overlaps substantially with the manufacturing, durability and hygrothermal sessions, to the point where raw-earth construction is no longer a neighbouring discipline but a core part of engineered bio-based construction. Bio-stabilisers and the 3D printing of stabilised earth have largely removed the distinction between “raw” and “engineered” earth.

Mycelium is one of the most closely followed materials in the corpus, and it is important to be precise about what the evidence does and does not show. Roughly seven papers across three sessions now treat it. What is established is reproducible thermal performance in the laboratory, the feasibility of making basic blocks for tropical and temperate climates, and a first attempt at controlling its hygroscopicity with silica sol-gel coatings. What is not established, and we say so plainly in Section 5, is scale-up beyond decimetre-sized samples, fire behaviour under standard tests, batch-to-batch reproducibility in industrial conditions, and what to do with the material at end of life.

3D printing is becoming a widespread fabrication method rather than solely a research topic. Rice-husk concrete, geopolymer–earth mixes, bio-stabilised clay, multilayer lime-cement-PCM enclosures and stabilised earth are all now printed and tested, each borrowing the same fresh-state vocabulary of yield stress and buildability. The printable bio-mix has become a sub-field of its own.

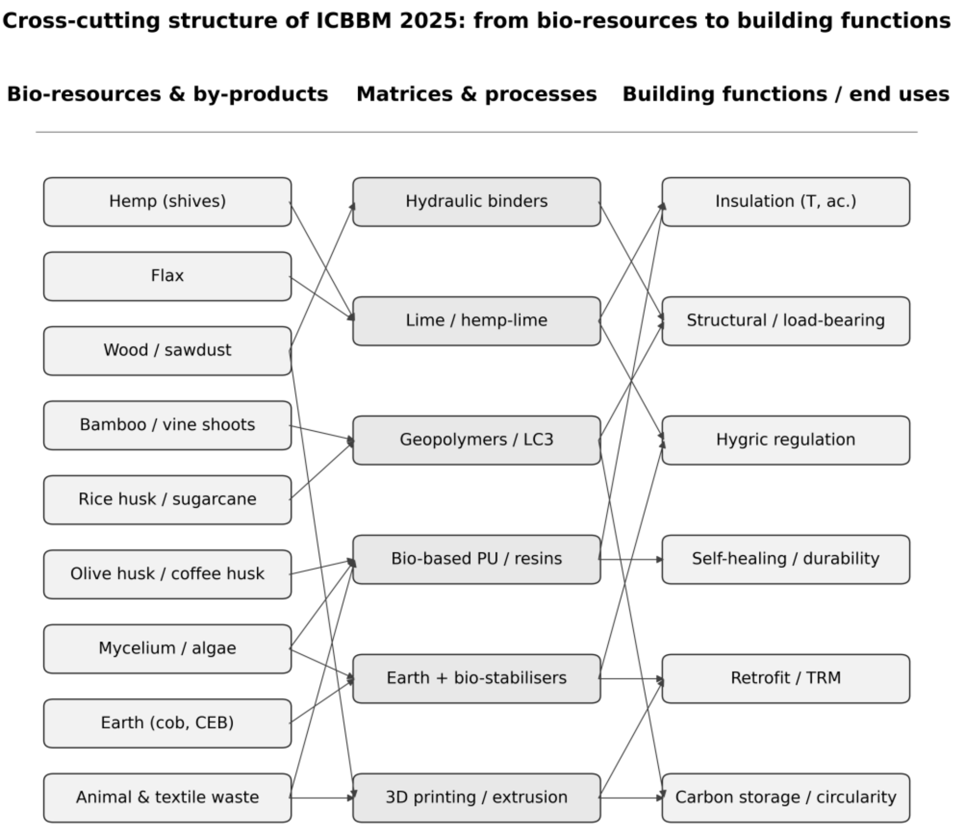

Figure 2. Cross-cutting structure of the ICBBM 2025 corpus, organised from bio-resources through matrices/processes to building functions. The same bio-resource is increasingly mobilised in several matrix systems and several end-uses simultaneously.

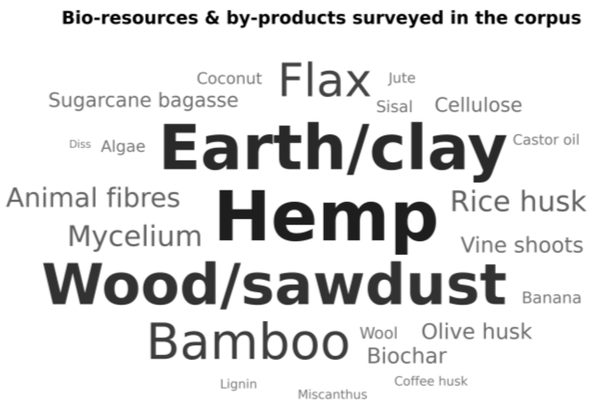

Figure 3. Bio-resources reported across the 144 ICBBM 2025 papers; bubble area approximates citation frequency.

Durability is the variable that ties the corpus together, though it is never quite measured the same way twice. It shows up as alkaline ageing in fibre-cement systems, as biological attack in earthen and bio-aggregate matrices, as hygrothermal cycling in envelopes, as capsule integrity in self-healing concretes. Self-healing belongs here too, as the active face of the same problem: MICP, EICP, hydrogel delivery and encapsulated agents are, in the end, ways of making durability something the material manages itself rather than something it merely has.

A further, less visible change is under way: RILEM technical-committee work, TC 236-BBM and TC 107-CSP especially, is increasingly the common methodological ground. It allows results from Brazil, France, Italy, the UK or India to be compared directly. A useful way to gauge how mature a session really is, in fact, is to count not its papers but the share that cite a recognised RILEM, ISO or CEN protocol. By that measure, the mechanical session leads, the LCA session trails, and the bio-binders sit somewhere in between.

5 Current gaps

Taken together, the 144 contributions make the field's gaps as visible as its progress. We see nine of them, structural rather than incidental, together with three deployment barriers the technical literature has largely treated as someone else's problem. Figure 4 summarises how each gap relates to the developments we expect to address it; here we set out the gaps themselves, and the direction each one points to, in plain terms.

Long-term durability data remain scarce. Most durability conclusions in the proceedings rest on accelerated tests run over weeks or months, while multi-year monitoring of bio-aggregate concretes, hempcrete walls and earthen envelopes under real climates and microbial pressure is still the exception. Until that evidence exists, service-life predictions stay conservative and insurers, code-writers and owners stay cautious.

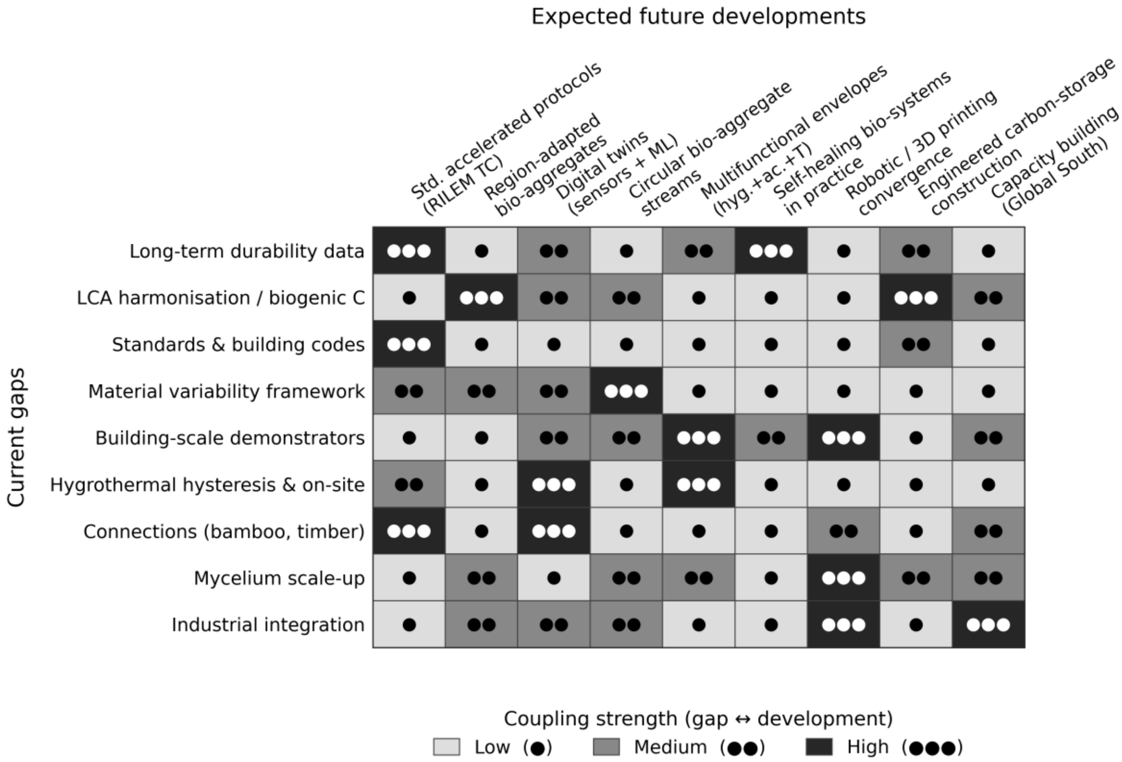

Figure 4. Qualitative mapping of the current gaps in bio-based construction (rows) to the expected future developments (columns) of Section 6. Bullet density indicates the strength of the expected linkage; every linkage is explicitly developed in §§5–6.

Life-cycle assessment is not yet harmonised, in particular with regard to biogenic carbon. The dedicated session, with the LCA components of the structural papers, shows persistent disagreement over functional units, system boundaries, the treatment of biogenic carbon, end-of-life scenarios and land-use change [Santana & Ouellet-Plamondon]. When two studies of nominally identical hempcrete walls differ by an order of magnitude, the field cannot take part in the quantitative climate-policy debates that depend on auditable carbon accounting. This requires a shared accounting convention, developed jointly with environmental engineers rather than by materials scientists alone.

Standards and building codes lag behind the laboratory. Several papers on bamboo connections, full-culm systems and low-carbon housing note that local codes either ignore bio-based materials or address them only in general terms, leaving a chronic gap between what can be demonstrated and what a designer is allowed to specify. Closing it means tying RILEM and parallel normative work (ISO, CEN, national bodies) much more tightly to the academic effort these proceedings represent.

The variability of biological raw materials is not yet handled statistically. Bulk density, initial rate of absorption and thermal conductivity vary considerably between batches and between regions, yet frameworks that carry that variability through to component performance are rare. What is needed is region-by-region property bands, statistically characterised, in place of single global recipes.

Building-scale demonstrators are too few. The corpus holds some excellent on-site studies (straw walls, the Paris earthen structure, urban heat-island mitigation), but most evidence stops at material or component scale. The field needs more long-running, instrumented buildings monitored in real use, with indoor climate, energy and durability measured over years, since whole-building performance claims currently rest on component-scale evidence alone.

Hygrothermal hysteresis is rarely validated on site. Models that include hysteresis explicitly and are checked against multi-year field data are still uncommon, despite how much moisture buffering matters for comfort. This is partly a modelling problem and partly a consequence of the demonstrator gap above.

Connections remain the structural bottleneck. Across the structural session and two systematic reviews, the joints in bamboo and timber-bamboo systems come up again and again as the weakest link.

Mycelium still has four unresolved engineering questions. Before it can be deployed, it must answer scale-up beyond decimetre samples, fire reaction under standard tests, batch-to-batch reproducibility in industrial production, and end-of-life management.

And, underpinning the rest, the field's disciplines and its industry are too weakly integrated. The fragility of the LCA work is as much organisational as methodological: materials laboratories, environmental-engineering groups and industrial-ecology teams still collaborate unevenly, and the same holds at the materials–regulation and materials–economics interfaces. The corpus also reflects structural biases linked to language, conference access, travel funding and existing citation networks; these are not faults of individual papers, but they affect the visibility of regional knowledge and should be acknowledged in any rebalancing of the field. Without sustained, multi-year integration through joint doctoral programmes, mixed RILEM committees and shared publications, the field's environmental and economic claims will stay contestable.

We treat three deployment barriers at the same level as the technical gaps. Cost competitiveness is barely addressed: unit-cost benchmarks against conventional products appear in only a handful of papers [Koster], and without explicit life-cycle costing (production, logistics, installation, maintenance), claims of competitiveness rest on assumptions procurement teams will challenge. Supply-chain scalability is almost absent: whether enough hempcrete, mycelium blocks, stabilised earth or natural fibres can be produced at the volume, quality and lead time a national building programme needs is a question the corpus barely asks, and the diversification shown above (Fig. 3) also has a downside, spreading the supply chain across more resources than any one market can sustain. And demonstrator financing falls into an awkward middle ground, too applied for fundamental-research funding, too pre-commercial for industry, that the academic community cannot bridge on its own. Treating these three as outside the field's scope repeats a documented pattern in innovation studies, the valley of death separating invention from market deployment [Auerswald & Branscomb], from which bio-based construction is unlikely to be exempt.

6 Expected future developments

The same proceedings that surface the gaps also show how the community is preparing to close them. We set out nine pathways below, each a response to a specific gap of Section 5 rather than a free-standing aspiration. The carbon-storing pathway (6.8) comes last and at greater length, because we think it is the strategic argument of the field for the coming decade.

6.1 Standardised accelerated and long-term protocols

Building on RILEM TC 236-BBM, TC 275-HDB, TC 282-CCL and successors, the next two years will likely produce harmonised protocols for ageing of bio-aggregate concretes, durability of plant-fibre reinforcement, on-site hygrothermal monitoring and binder–plant-particle compatibility. This pathway directly addresses the long-term durability and standards-and-codes gaps; it also underpins LCA harmonisation by stabilising the inventory inputs.

6.2 Climate-region-adapted bio-aggregates

Tropical regions will further engineer rice husk, coffee, sugarcane bagasse, banana, piassava and tropical bamboo systems; Mediterranean regions will consolidate olive-husk, vine-shoot and miscanthus chains; Northern Europe will continue with hemp, flax, wood, wool and seagrass. The directly addressed gap is biological variability: explicit, region-by-region property bands replace single global recipes.

6.3 Digital twins of bio-based buildings: anchored, not assumed

We treat digital twins as a credible direction rather than a foregone conclusion. The verifiable milestones over the next four to six years are: (i) public availability of multi-year hygrothermal monitoring datasets from instrumented bio-based buildings, of the kind initiated by the on-site straw monitoring reported here [Achour et al.]; (ii) cross-laboratory validation protocols for hygrothermal models that include hysteresis, building on the modelling session of these proceedings; (iii) integration of self-sensing concretes (the bio-carbon-fibre composites already reported here) with low-cost wireless monitoring at element scale; and (iv) data-driven surrogates trained on the experimental databases that ICBBM has been producing for a decade [first attempt: Tedjditi & Kaouane]. Without these intermediate milestones, current use of the term “digital twin” is not yet supported by the validation evidence it implies. The directly addressed gaps are building-scale demonstrators and hygrothermal hysteresis.

6.4 Circular bio-aggregate streams

Sewage-treatment-plant sludge, malt bagasse, recycled textile waste, animal fibres, ornamental-stone waste and end-of-life timber/composite reuse are already in the corpus. The next step is the systematic mapping of urban and agricultural by-product streams to specific bio-binder, bio-composite or earth-stabilised products, an explicit industrial-ecology overlay on top of the materials science. This pathway is one of the natural responses to the supply-chain scalability barrier identified above.

6.5 Multifunctional building envelopes

Several papers already demonstrate that the same bio-based wall can deliver mechanical, thermal, hygric, acoustic and (via PCM) latent-heat services. The next generation of envelopes will explicitly trade off these functions, including health-related performance (VOC reduction, biophilic effects), with multi-objective optimisation routinely embedded in design. The directly addressed gap is the building-scale demonstrator gap: only multifunctional, instrumented demonstrators can substantiate the joint performance claims.

6.6 Self-healing bio-cementitious systems in practice

MICP, EICP and hydrogel-based healing have moved from laboratory to engineering questions. The expected step is the inclusion of self-healing as a service-life parameter in design, particularly for recycled-aggregate or bio-fibre-reinforced concretes. This pathway addresses the long-term durability gap by reformulating it as an active rather than a passive property of the material.

6.7 Robotic and 3D-printing convergence

Printable rice-husk concrete, mycelium-cellulose composites, bio-stabilised clay, multilayer lime-cement-PCM structures and stabilised-earth carbon-storing prints all appear in these proceedings. Convergence with robotic fabrication will allow envelope morphologies that exploit anisotropy intrinsically rather than fight it. This pathway is one of the strongest responses to the biological-variability gap, because robotic placement can be tuned to local material properties batch by batch.

6.8 Engineered carbon-storage construction: the strategic reframing

We close Section 6 with the pathway that we judge to be the strategic argument of bio-based construction for the coming decade: the explicit reframing from “low-carbon” to “carbon-storing” buildings. The corpus contains all the ingredients for this reframing, but it is rarely articulated as such. We articulate it here in four parts.

6.8.1 Sequestration potential at material scale

Plant-derived bio-aggregates carry 35 to 50 % carbon by dry mass, biochar 70 to 90 %, lignin around 60 %. Mycelium sits close to the bio-aggregate range, roughly 40 to 48 %, reflecting its chitin-glucan composition, while algae vary far more widely than a single figure suggests: non-calcified species reach 40 to 50 %, but calcifying macroalgae can fall below 20 % once mineral content is accounted for. A wall built with bio-based aggregates and bio-additives at typical dosages can act as a net carbon sink at the element scale, even after embodied emissions of the binders are accounted for; several earth-based and hempcrete contributions in the corpus already report negative cradle-to-gate values. At gigatonne-relevant scale, the construction sector globally consumes enough material per year for bio-based envelopes to operate as a meaningful biogenic-carbon reservoir.

6.8.2 Permanence across the life cycle

The credibility of carbon-storage claims depends on residence time. Buildings designed for 50–100 year service lives convert short biogenic-carbon cycles (annual to decadal in agriculture) into multi-decadal storage. The corpus directly bears on this point: the durability papers (§3.8) and the hygrothermal-on-site monitoring (§3.11) provide the empirical underpinning for permanence claims. Conversely, materials whose service life is shorter than their carbon-payback time do not store carbon, they delay its release. The community needs explicit, material-by-material storage-time accounting; it does not yet exist consistently.

6.8.3 End-of-life scenarios

Combustion, landfill, reuse and cascading each yield different carbon outcomes. Combustion releases the stored carbon (climate-neutral at best); landfill behaviour depends on degradation conditions; reuse and cascading extend storage by additional service lives. Biochar end-of-life is the outlier: its recalcitrant chemistry implies near-permanent storage even after building demolition. End-of-life scenarios are unevenly treated in the corpus and constitute the single most important uncertainty in any carbon-storage claim. They are therefore the natural junction between this pathway, the LCA harmonisation gap (§5) and the circular bio-aggregate streams pathway (6.4).

6.8.4 Implications for certification frameworks

Current European product-EPD frameworks (EN 15804+A2) treat biogenic carbon with a -1/+1 convention that, in many implementations, nets out the storage benefit unless storage permanence is explicitly modelled. National building-regulation low-carbon schemes (e.g. RE2020 in France) increasingly recognise biogenic stocks but with very different conventions. A field that wants to defend its strategic argument needs to participate, with environmental engineers and certification specialists, in the harmonisation of these frameworks. The cross-disciplinary integration gap of §5 and the carbon-storing reframing therefore reinforce each other: the technical reframing only becomes a market lever once the certification frameworks are aligned.

6.9 Building on Global-South knowledge, not importing into it

Hosting ICBBM in Rio mobilised Latin-American and African groups whose vernacular and empirical knowledge of earth, bamboo and plant fibres long predates the European research programme. The pathway here is less about "integrating" that knowledge than about giving it equal standing, through joint doctorates, RILEM participation and regional pilots, so the more disruptive of the two research directions identified in Section 2 can develop design rules grounded in local practice.

7 Conclusion: from low-carbon to carbon-storing construction

ICBBM 2025 in Rio de Janeiro is the edition at which bio-based building materials research grew well beyond its original scope. With 144 contributions, eleven thematic sessions, and a markedly more global participation, the proceedings document a field moving from laboratory demonstration toward early deployment, while still lacking robust building-scale evidence. Read editorially, the eleven sessions sit at very different maturity levels, with internal contradictions, most visibly between binder systems on plant-fibre durability, that the next two ICBBM cycles will need to resolve methodologically rather than rhetorically.

The nine structural gaps and three deployment barriers set out in Section 5 form the field's agenda for the next research cycle. They reflect a field moving from laboratory validation toward market adoption, not a lack of progress. Underpinning all of them is the need for closer, sustained collaboration with the environmental-engineering, regulatory and economic communities. The developments outlined in Section 6 are not speculative: each is already rooted in papers presented in Rio.

The strategic argument that we believe the field should adopt and defend over the coming decade is the reframing of bio-based construction from "low-carbon" to "carbon-storing". The technical building blocks are present in the corpus, sequestration potential at material scale, life-cycle permanence anchored in durability and on-site evidence, end-of-life scenarios that distinguish delay from storage, and certification frameworks that need to recognise permanence explicitly. Mobilised together, these elements make it possible to recast buildings as engineered carbon sinks at the gigatonne scale, complementary to nature-based solutions and reductions at the cement plant. ICBBM 2027 will return to Europe; by then, we expect the field to have moved another decisive step from "bio-based construction is possible" to "bio-based construction is the default for low-carbon, comfortable, healthy and carbon-storing buildings". The 1788 pages produced in Rio strongly suggest that this shift is no longer aspirational.

Authorship statement (CRediT)

Sofiane Amziane: Conceptualization; Investigation; Coordination; Visualization; Writing - Original Draft. **Romildo Dias Toledo Filho:** Investigation; Visualization; Writing - Original Draft. **M'hamed Yassin Rajiv da Gloria:** Investigation; Visualization; Writing - Original Draft. **Jonathan Page:** Investigation; Visualization; Writing - Original Draft.

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