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URBAN MINING 1.0: DECOLONISING GENERATIVE DESIGN THROUGH BIOMIMETIC-CULTURAL SYNCRETIC ARCHITECTURE

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ABSTRACT
Biomimicry architecture promises to synthesize ecological principles and computational efficiency, yet risks marginalising vernacular knowledge systems via universalist optimisation logics. Analysing precedents in Chinese and Jordanian scholarship reveals the imperative to embed both environmental and cultural contextual intelligence into computational workflows, countering colonial residues inherent in standardised design. Employing a Research-through-Design (RtD) methodology, the study develops a modular system, subsequently infused with traditional patterns (Phase I & II), and integrates physics simulations to foster structural emergence from cultural motifs (Phase III). This culminates in applying the refined pipeline to design an orthopaedic hospital in Jordan, synthesising algorithmic generation with indigenous geometric traditions. Crucially, the investigation proposes and applies a novel "roots-residue-resistance" (3R) framework, evaluating cultural rootedness, colonial residue, and community resistance as a decolonial audit tool for designer self-reflexivity. The findings advocate for a biomimetic-cultural synthesis that positions vernacular knowledge as vital resources ("urban mines") for sustainable architectural production, thereby challenging homogenisation and promoting epistemic justice within computational design praxis.

Keywords: Biomimicry, Decolonial Praxis, Generative Design, Vernacularity, Modular Systems

1 INTRODUCTION

Biomimicry architecture is a design approach that looks at how nature functions, learning from the Earth's 3.8 billion years of evolutionary R&D. For instance, ICD Stuttgart's (2015) research pavilions emulate natural organisms that use minimal material for maximum strength, such as sea urchins and water spiders. These designs are increasingly facilitated by generative methods, which encode natural processes and systems through algorithmics, creating designs based on predefined rules, goals, and parameters. Recent projects have sought to balance nature-culture synthesis by introducing socio-contextuality into generative biomimicry design: Gilles Retsin (2019) showed how discrete computation can encode digital craftsmanship, leveraging bottom-up biological intelligence to automate construction, while Daniel Kohler (2017) introduced a mereological approach to urban design, compositing cities with pattern thinking on part-whole relationships.

These efforts contributed to an ecological understanding of architecture as systems and demonstrated innovative prospects in balancing human agency with machine automation. However, these projects were largely based on rigorous formal, analytical philosophy of European roots, which build synthesis from dichotomies. Applying these methods outside western contexts without critical reflection could risk marginalising vernacularity. Our study therefore focuses on post-colonial contexts, learning from international precedents while centering on means to confront the eurocentric tendencies of generative culture. ***How to embed contextual intelligence, both environmental and cultural, into generative workflows by integrating biomimicry and vernacular paradigms***? The goal is to propose a decolonial framework to resist normative designs while preventing cultural appropriation. Theoretically, to provoke a critical re-examination of how architects appropriate inspirations from diverse cultures. Practically, to propose a computational framework generalisable to other postcolonial contexts. This investigation

views vernacular culture as “mines” rich in inspirational resources to be reclaimed and reintegrated into contemporary architectural production cycles—a form of urban mining.

2 COMPUTATIONAL DESIGN THROUGH DECOLONIAL PRAXIS

Generative urbanism is shown to perpetuate colonial epistemologies by prioritising standardisation and scalability over cultural specificity. Scholars such as Arturo Escobar (2018) and Walter Mignolo (2011) critique the universalisation of Eurocentric optimisation logics, which marginalise vernacular knowledge systems through reductionist material workflows. This highlights a critical gap in applied computation for embedding indigenous practices, as evidenced by scholarship demonstrating how algorithmic frameworks can marginalise local roots: Hao (2024) showed this in digital content creation; Chu (2013) debunked how sanitising design was used as a form of regulation in colonial Hong Kong; Kizhner et al. (2020) measured bias in aggregated Google Art content as colonial residue; and Rabady & Khafajah (2021) detailed how colonial legacies shaped heritage governance in Amman.

In response, design scholarship has focused on actionable pathways to decolonise. Ng (2025) discussed building a non-European vocabulary base as a form of community resistance, while Maasri (2020; 2021) argues that ornament is not a crime but a means of asserting cultural sovereignty. Liu et al. (2025) deployed digital humanities to mitigate conflicts where Western AI reduces traditional art to superficial filters, and Abdulla (2019) calls for Jordanian design education to promote critical inquiry over technical skills. Nonetheless, modernity injects complexity in defining the local from the colonial, as shown by Shawash (2021), who analysed the synthetic modernist architecture from Jordan's British Mandate period. This complexity warns that an emphasis on ‘authentic’ symbolism risks ossifying cultural practices by neglecting dynamic reinterpretations that align with design justice principles.

3 METHODS

The literature exposes a paradox within decolonial design: the attempt to subvert technocratic paradigms through tools inherently shaped by “the expert gaze”. While encoding vernacular knowledge into algorithms offers resistance to epistemic colonialism, it simultaneously risks co-option into expert-led frameworks that commodify cultural difference. In synthesising emerging themes of culture-nature through design, the methodology employs a phased Research-through-Design (RtD) approach that cyclically interwove design phases with critical decolonial evaluation.

Table 1. A roots-residue-resistant framework for agency audit.

Axis	**Question**	**Scoring**	**Visible Indicators**
Cultural Roots	How deeply does the design reflect local culture?	1 = Foreign (Feels imported/imposed) 3 = Familiar (Recognizable elements) 5 = Ancestral (Feels born from our land)	Forms: brutalist blocks vs. organic curves Patterns: authentic motifs vs. abstract shapes
Colonial Residue	Does the design erase the complexity of today’s globalised reality?	1 = One-sided (A simple, binary judgement) 3 = Partial (Attempted bilateral verdict) 5 = Balanced (Synthesised epistemic justice)	Materials: local stone/wood vs. steel/glass Ornament: "exotic" clichés vs. meaningful symbols
Community Resistance	How much does the design distort (hide, conflat, romanticise) local history?	1 = None (Feels like oppression) 3 = Noticeable (Mixed messages) 5 = Strong (Our voice is clear)	Function: ignores local climate/traditions. Spirit: sacred geometry/ flow vs. rigid grids

This experiment synthesises our digital algorithmic approaches with indigenous geometric traditions, with all generative results undergoing a custom "Agency Audit" through the proposed roots-residue-resistant framework to review the design outcomes:

- **Phase I** developed an interlocking modular system, generalisable to diverse pavilion construction contexts, while interrogating standardisation-localisation balance.
- **Phase II** infused the system with traditional patterns, examining risks of ornamental tokenism
- **Phase III** applied physics simulation from growth algorithms to counteract the universalist approach to structural engineering that often stifles vernacular inspirations.

Finally, the study consolidates all lessons learnt into a design pipeline and applies it in a real-world architectural context, designing an orthopaedics hospital for a Jordanian client.

4 RESULTS

4.1 Phase 1: Modular System, Geometry, and Adaptivity

Phase one was the inaugural work in a series influenced by biological morphology to design an interlocking modular system as a proxy adaptive to diverse cultural upscaling and production contexts in subsequent investigations. The piece is constructed using precisely rationalized geometries and is assembled without adhesive material; instead, it utilises interlocking connections that allow it to be fully disassembled for maintenance of its internal electrical components. Its overall form is derived from a parametric three-dimensional model that is converted into flat geometries, enabling a mechanical-style assembly. A dovetail joint system is employed along the curved branch elements, capitalising on the inherent elastic bending properties of the cardboard to maintain tension and achieve the desired three-dimensional shape as the flat-cut plates interlock. The design draws inspiration from Haeckel's (1899) biological lithographies, traditional Chinese interlock joinery, as well as contemporary active timber techniques (Correa, Krieg & Menges, 2016).

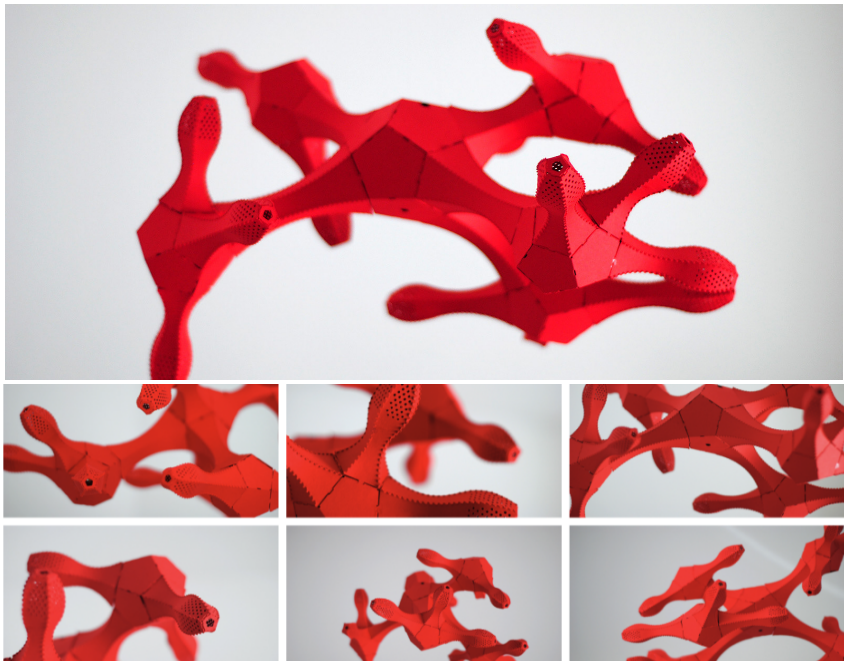

Figure 2. An interlocking modular system as an adaptive proxy, fusing biological lithographs.

4.2 Phase 2: Patterns, Physics, and Emergence

In phase two, the interlocking typology's pattern formation is used to infuse cultural symbolism, beginning with a continuous curve constructed via the Hilbert space-filling method; loads and boundary conditions were applied by fixing anchor points, predominantly on the periphery, and imposing gravity on each vertex of the Hilbert curve. This experiment proposed that, akin to traditional Chinese architectural culture where edges bear unique loads and decorative prominence, structural performance could emerge from anchoring non-classical points. The interplay of gravity vectors and global geometry allowed emergent spatial qualities to manifest: gaps arise between dense- clustered segments of space

filling Hilbert curve, whose locality mirrored the spatial logic in Chinese structures whereby larger constructions are composed of smaller, locally responsive elements adaptive to manufacturing constraints and needs for shock absorption and component replaceability.

A salient innovation was the interlocking joint design, where twist operations generated mechanical connections whose inherent curvature introduced tension, stabilising both joint and curved surface; pre-tensioning components in this way yielded robust connections, echoing artisanal traditions and providing a blueprint for future prefab, scalable design, thus reiterating that intelligence in geometry persists across time, with modularity and resilience rooted in making do with available means. This approach offers practical value not only for its physical and engineering properties—chiefly, the localised containment of potential structural failures—but also for reflecting the historical aesthetics of "flying eaves" (飞檐), the elegant curved roof edges that extend upward and outward as a form of biomimicry of bird tails to direct wind and water, often found in drizzling regions like Suzhou to protect structures from rain and allow natural light penetration, demonstrating how geometry operates simultaneously as inherited natural wisdom and contemporary cultural innovation.

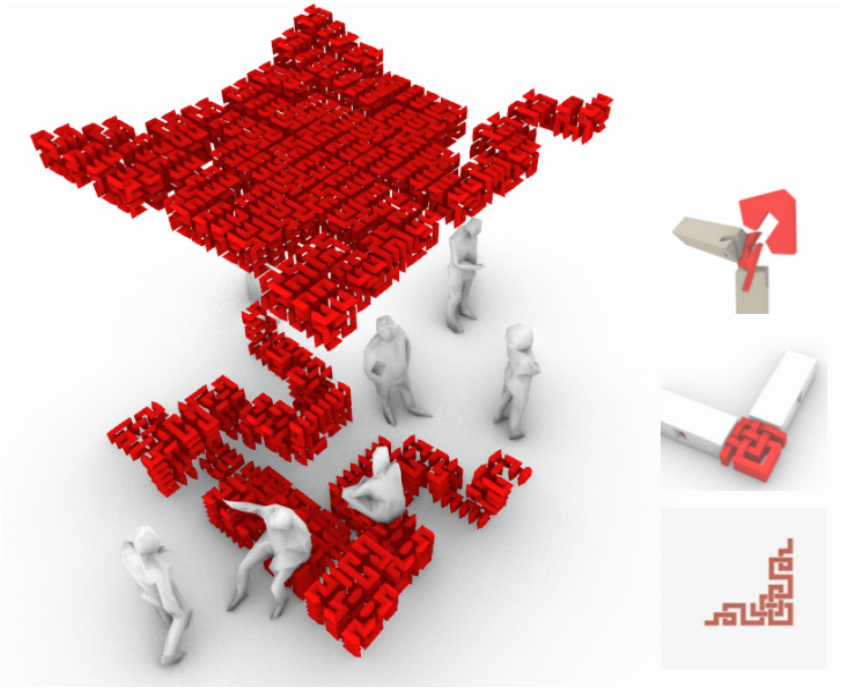

Figure 3. Phase two infuses cultural symbolism through pattern formation.

4.3 Phase 3: Biomimicry, Diversity, and Structure

Phase three tried to diversify the solution space, testing the pattern-driven modular logic under both tension and compression dynamics. The interplay between physical forces and cultural patterns taking centre stage to reconstruct organic forms, through growth simulation of branching formations to generate structurally stable designs. Sections of the original structure were abstracted and underwent physics simulations to test their structural behaviour when elevated from the ground—mirroring a real test of pattern as structure. This led to emergent webs connecting disparate fragments that, under simulated growth and gravitational forces, revealed where patterns would naturally meet the ground as supports. The green indicators in the simulation reflected algorithmically optimised load transfer, producing a visually legible relationship between pattern and structural support. Further experiments examined the effect of load transfer along defined axes—such as the X and Z directions—by leveraging pattern symmetry. Intuitive understanding was often upended by computational results, demonstrating non-uniform load transfer and new possibilities for emergent form-finding in architectural systems. Through these exercises, it was clear that employing different physical forces (not merely tension) prompts genuine emergence within patterned structure, providing deeper insight into the underlying physics of ornament and its potential for contemporary application.

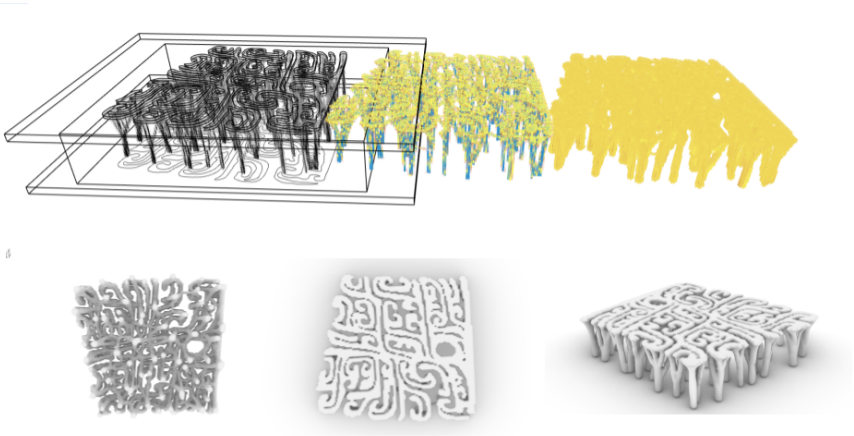

Figure 4. Pushes the solution space, integrating branching structures with pattern systems.

4.4 Phase 4: Synthesis

Integrating insights in façade design, functionality, and load transfer, Phase 4 focused on a real-world orthopaedic hospital project in Jordan where internal machinery imposed substantial structural demands; by applying defined point forces to the underlying geometry based on machine placement and eliminating superfluous material, the algorithm yielded lightweight, optimised, and biologically informed design: façades referencing human biology via its functional load-bearing characteristics.

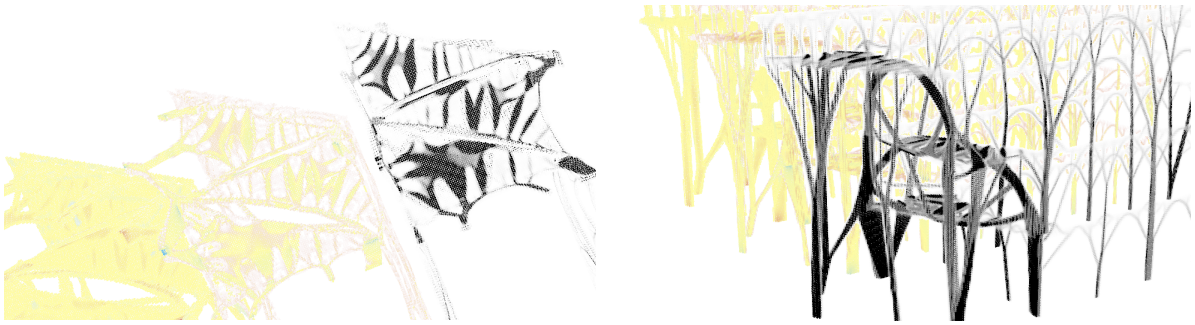

Figure 5. Pattern system fuses bone lattice and islamic arches for optimal load distribution.

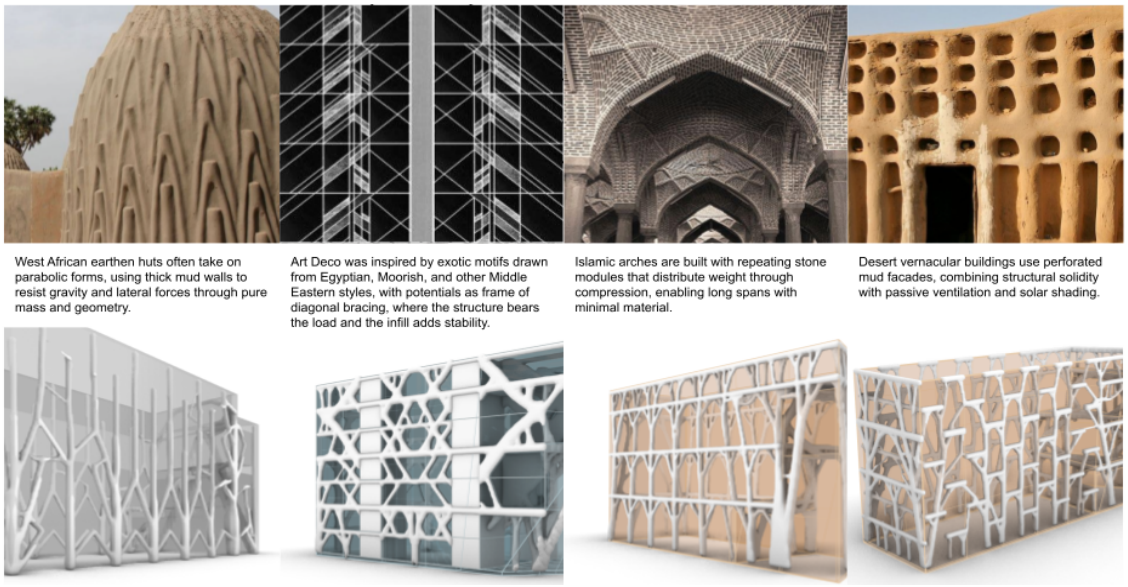

Figure 6. Vernacular strategies epitomising resilience in resource-limited climates.

The project drew from localised generative design translating traditional two-dimensional cultural motifs (including perforated mud buildings, local interpretations of African parabolic forms, and Islamic

arches) into three-dimensional geometries optimised for structural load requirements, with each evolving pattern treated as an emergent property of materiality. The culturally-inspired visual complexity of geometric patterns was juxtaposed against conventional load transfer systems, with the pattern responding variably along different floors and directions (X, Y, and Z) to reflect dynamic load distributions reminiscent of adaptive bone structures, where tension and compression are unevenly allocated; an interesting observation emerged regarding the binary nature of lattice placement, where, as in bone, the outer lattice differed from its interior counterpart due to distinct utility requirements. Notably, failures were also encountered. For instance, designs invoking historic arches were deemed aesthetically regressive by the client, while the Art Deco reference underscored the historic evolution of cultural patterns developed through colonial influences.

5 DISCUSSIONS

Based on a structured audit according to the root-residue-resistance framework, the experimental phases demonstrate a clear trajectory:

- Phase 2 and Phase 4 excel most robustly in embedding deep cultural roots and ensuring community voice, with
- Phase 4 achieving the highest agency through sustained co-creation with local materials and motifs, and a direct decolonial critique that renders the design inseparable from its cultural, material, and social context. In contrast,
- Phases 1 and 3 show middle scores, wrestling with abstraction and universality in a hybridization that sometimes sidelines rooted expressions for algorithmic or biological logics.

This visible progression highlights how iterative refinement shifts the work from abstracted hybrid logics toward context-specific, community-responsive architectures, demonstrating the critical significance of procedural design iteration with structured reflexive practice in post-colonial contexts. Overall, the project increasingly achieves "agency" as it moves toward rooted productions, though the audit crucially warns that diversifying the solution space—as in Phase 3—can risk reverting to colonial motifs through the simplification of vernacular features, underscoring the perpetual need for safeguarding measures.

Table 2. Agency audit for Phase 1-4.

Phase	Axis	Score	Visible Indicators
Phase 1: Modular, Geometry, Adaptivity	Roots	3	Blends traditional joinery and biomorphic geometries; fuse parametric with organic.
	Residue	3	Hybrid techniques; fails to synthesize cohesively; non-local materials.
	Resistance	3	Adapts local assembly methods; but in an abstracted, romanticized way.
Phase 2: Patterns, Physics, Emergence	Roots	5	Combines structural symbolism and cultural forms; Hilbert curves and "flying eaves".
	Residue	3	Functional elements (e.g. rain protection) for symbolism; synthesis incomplete.
	Resistance	5	Structure-function integration echoes artisanal wisdom; pattern logic infuse local voice.
Phase 3: Biomimicry, Diversity, Structure	Roots	3	Branching logic is cross-cultural, but not tied to a specific ancestry. Algorithmic geometry references organic traditions while remaining abstract.
	Residue	3	A partial global-local balance. Result perceived as universally "scientific" rather than culturally specific. Symbols are functional, avoiding "exotic" connotations.
	Resistance	3	Physical-ornamental logics avoid romanticisation. Generically “biological”, histories flattened. Local climate / traditions respected; “spirit” may be diluted.
Phase 4: Façade, Functions, Optimisation	Roots	4	Design for Jordan, vernacular facades, local motifs, Islamic arches, adapts into functional, structurally-optimized geometry / ornament.
	Residue	4	Addresses colonial patterns (pushback on Islamic arches, acknowledgment of Art Deco as colonial residue). Epistemic justice via local motif formalization; context-specific.
	Resistance	4	The façade adapts vernacular logic to modern requirements (structural loads, bone lattice optimization). Local climate/context is foregrounded.

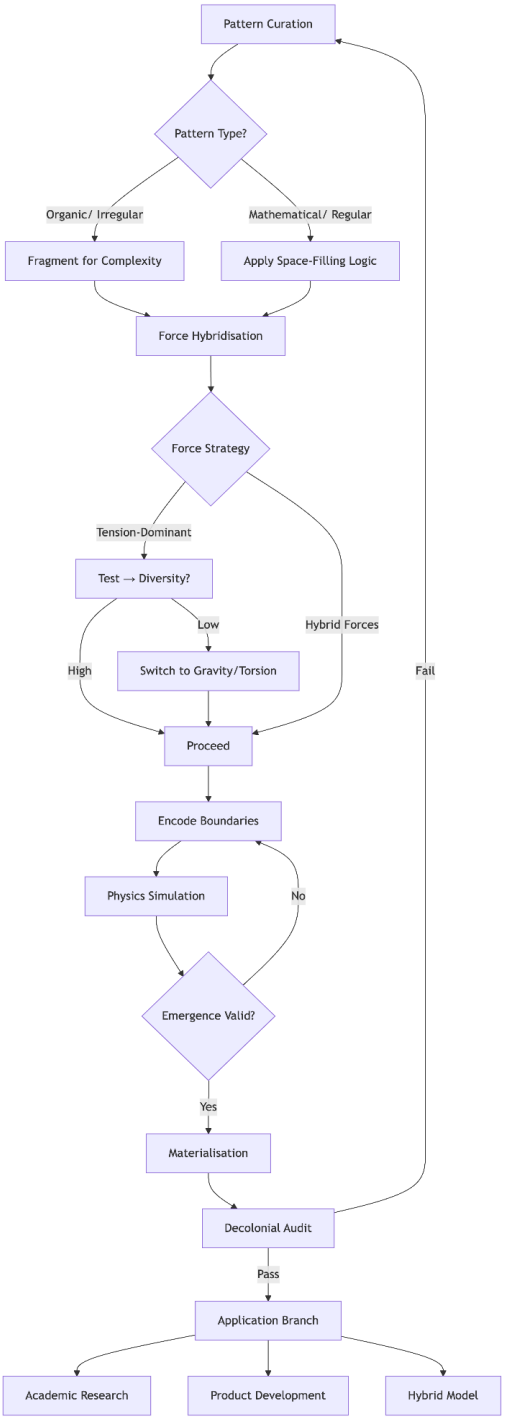

Figure 7. Decision pathways in the emergent design process.

6 CONCLUSION

By framing colonial legacies in architecture as the hegemonic persistence of universal design paradigms that systematically erase cultural specificity, the study proposes a counter-praxis of agency audits. Demonstrated via a case study that synthesizes biological intelligence with vernacular elements to develop tectonic systems that resist abstraction, this method transmuted two-dimensional cultural patterns into three-dimensional structures that are culturally and materially responsive to gravitational forces and tension, embodying both local memory and physical logic. The research consciously positions itself against orientalist appropriation through a 'generative syncretism': a protocol demanding documented cultural stewardship and algorithmic transparency, fundamentally challenging extractive design practices. However, the computational tools employed remain embedded within power asymmetries, while practical constraints such as construction regulations mandating foreign engineering collaboration expose the neocolonial structures that persist within globalized practice. The study

acknowledges its complicity in potentially reproducing the universalizing tendencies it critiques, specifically through potential urban-rural biases, the romanticization of artisanal labor, and the simplification of complex post-colonial identities. Ultimately, it argues that without such critical frameworks, computational architecture inevitably reinforces neo-colonial norms, but through rigorous self-reflexivity and acknowledgment of globalized material cultures, it might yet cultivate more equitable, contextually-grounded architectural futures.

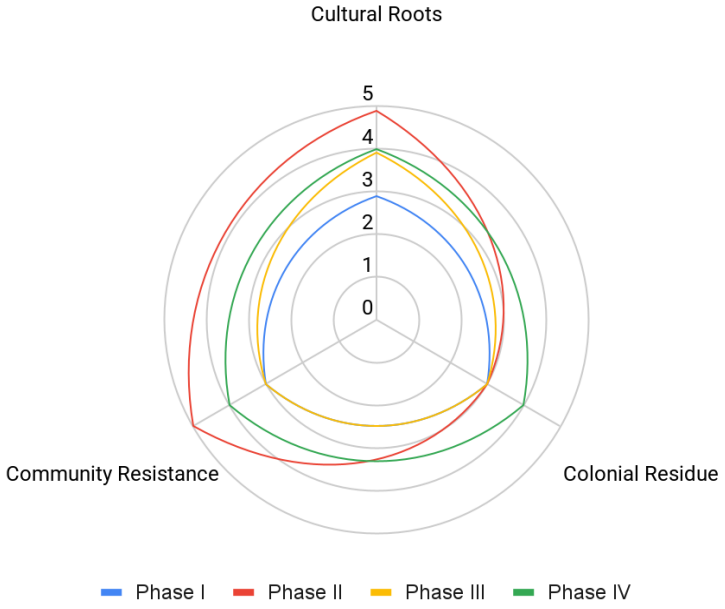

Figure 8. Agency Audit Results by Phase.

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