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MATERIAL TRADITIONS, CRAFT, AND INDIGENOUS KNOWLEDGE SYSTEMS

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Traditional Dwellings and Settlements

Working Paper Series

EMBEDDED GEOLOGIES: MATERIAL TECTONICS AND CRAFT TRADITIONS OF KADAPA STONE, INDIA

Lingala Siva Deepti Reddy, Sheth Kinjal Nitinkumar

EMBEDDED GEOLOGIES: MATERIAL TECTONICS AND CRAFT TRADITIONS OF KADAPA STONE, INDIA



This paper examines Kadapa stone, a dense black limestone from the Cuddapah¹ Basin in Andhra Pradesh, and its formative role in shaping the built environment of semi-arid Rayalaseema region, especially Kadapa District. Focusing on material tectonics and building practices, it investigates how traditions persist, adapt, or disappear over time. This research adapts the Traditional Knowledge systems approach through field study, archival sources, and architectural documentation, to trace the practices from historical construction to contemporary interventions. It argues that Kadapa stone architecture translates geological landscapes into cultural landscapes through materially grounded practices.

1. INTRODUCTION

“History and tradition share positions of authority in most societies. Yet, while history’s authority lies in its knowledge production, tradition receives authority through the passage of time. Without dismissing the parallels between history and tradition, the book argues that the normative discourses that conceive of tradition as a place based, temporally situated concept, as a static authoritative legacy of a past, and as a heritage owned by certain groups of people cannot be sustained in the present moment of globalization.”

Nezar Alsayyad ²

Kadapa stone offers a strong case through which to examine this process. Although it circulated more widely across India from the mid-eighteenth century through colonial and modern construction networks,³ its most sustained architectural and tectonic traditions developed in *Rayalaseema*,⁴ particularly in the *Kadapa* district. Here, local quarry access, timber scarcity, and inherited stone-craft practices shaped its use as a primary building material (Figure 10). Valued for its strength, thermal performance, and resistance to weathering, it was traditionally used in load-bearing *antu middhe* (row houses) and *maadi middhe* (more than single story houses), temples and shrines, wells, irrigation canals, roads, bridges, mills, godowns, hospitals, schools, railway stations, and prisons.

The study adopts a diachronic, comparative approach to examine structures from different periods and understand how colonial building practices intersected with indigenous methods to produce hybrid forms, while also tracing contemporary adaptations and reinterpretations. Most of the structures studied are finished in exposed stone or lime wash, making details such as course type, stone size, and dressing clearly visible. A few dilapidated buildings are also included because they reveal construction technique and joinery more directly. Today, although no longer the dominant building material, *Kadapa* stone continues to be used

selectively in contemporary residences and temples, often reinterpreted through both traditional and modern idioms.

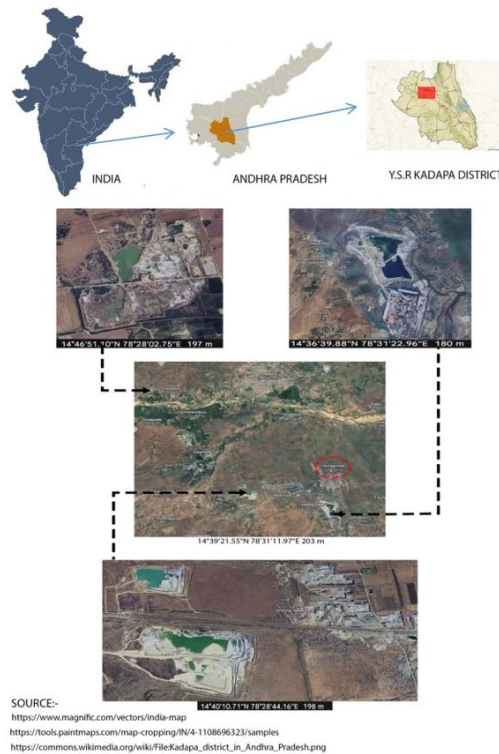


Figure 1: Geographical location of the study area. (Source: Google Maps, <https://www.magnific.com/vectors/india-map>, <https://tools.paintmaps.com/map-cropping/IN/4-1108696323/samples>, https://commons.wikimedia.org/wiki/File:Kadapa_district_in_Andhra_Pradesh.png).

While *Kadapa* stone has been studied for its material properties, its potential as a raw material for cement manufacturing, and the reuse of its scrap, the craft practices involved in its extraction, shaping, assembly, and architectural expression remain underexplored.⁵ This paper addresses that gap through fieldwork in selected settlements such as *Gotur*, *Proddatur*, *Yerraguntla*, *Chennur*, *Danavulapadu*, *Chilamakuru*, *Anladurthi*, *Gopavaram*, *Uppalapadu*, and *Jammalamadugu*, with attention to representative space-making elements in buildings (Figure1). Drawing on *Semper's* idea of material tectonics, the paper argues that architecture is shaped by the inherent qualities of materials and the crafts that transform them, and that expressive form arises from construction logic, material properties, and cultural symbolism.⁶

The documentation focuses on the stone tectonics of masonry, flooring and paving, roofing, foundations and plinths, openings, and staircases, alongside changing methods of extraction and use. It foregrounds indigenous craft knowledge held by quarry workers and stone masons, including the selection of stone strata, splitting and dressing of slabs, joinery, repair, and reuse. Transmitted through apprenticeship and oral

instruction, these practices reflect the agency of local artisans in shaping architectural meaning and continuity (Figure 10). Building on this, the study asks who drives these translations, who benefits from them, and which narratives of tradition persist, adapt, or disappear over time.

2. CONCEPTUAL FRAMEWORK

2.1. Vernacular Architecture and Transferred Traditions

Paul Oliver defines ‘Vernacular architecture comprises the dwellings and all other buildings of the people. Related to their environmental and contexts and available resources, they are customarily owner – or community built, utilizing traditional technologies.’⁷ So vernacular architecture is the product of collective knowledge, region specific practices and culturally shared building conventions. Amos Rapoport defines the term vernacular in terms of process – how it is designed and built. He further argues that vernacular architecture is the result of shared knowledge and collaborative process that is passed over many generations that is meant by the term ‘traditional’.⁸ The traditional architecture of *Kadapa* region developed through local quarry process, material availability and inherited craft process.

The knowledge of the indigenous building practices plays essential role and must be understood within the vernacular context. These practices emphasize skill, apprenticeship, and embodied knowledge rather than formalized professional systems. Quarry workers and masons have inherited the know-how of working with stone such as stone selection, splitting, dressing, and construction through collective knowledge and practice. Such knowledge is not only technical but also social, because it depends on collective memory, local adaptation, and repeated practice.

Tradition in this paper is understood not as a fixed inheritance from the past, but as something transmitted, interpreted, and continually reshaped through practice. Edward Shils defines tradition broadly as anything which is transmitted or handed down from the past to the present.⁹ Amos Rapoport sees vernacular building as a collective process sustained by shared values, conventions, and communal knowledge.¹⁰ The positioning of openings and interlocking of common walls in row houses in this region reflect that building activity is a community decision rather than based on individual’s perceptions.

A building tradition may be translated across time when materials, tools, labor systems, or social expectations shift, yet certain spatial logics or craft conventions remain recognizable. In Kadapa stone architecture, this can be seen in the movement from manual quarrying to mechanized extraction, from lime or mud mortars to cement-based repairs, and from older masonry conventions to contemporary reinterpretations. Tradition therefore becomes a process of negotiation between continuity and change, where some practices persist,

some are modified, and others gradually fall away. This paper uses translation to describe that active process of carrying tradition forward in transformed conditions.

2.2. Tectonics and Material Expression.

Kenneth Frampton examines and establishes the concept of tectonics which is poetics of construction – act of making a building with materials, structural logic, joints and craftsmanship. Rather than treating architecture as a purely visual or stylistic object, tectonic thought understands it as something produced through the meeting of material properties and making practices.¹¹ In the essay 'Structure, Construction and Tectonics', Eduard F. Sekler critically explores how tectonics is not merely a technical solution but rather it is a communicative medium as a rich cultural and aesthetic discourse that integrates form, materiality and meaning.¹² In this sense, tectonics becomes a critical framework for understanding the language of architecture that expresses and reveals how building practices give form to social meaning.

Gottfried Semper's writings provide an important foundation for this understanding. He addresses the language of tectonics is art of assembling stiff, 'plank like elements into a rigid system. He defines the process of building as joining material into an organized form.¹³ Semper's view that construction carries symbolic and cultural force is especially relevant to *Kadapa* stone, where the material is not simply assembled but worked through quarrying, dressing, coursing, bonding, and finishing. The visible logic of joints, the thickness of walls, the treatment of stone edges, and the relation between core and face all contribute to the architectural expression of the material. For this paper, tectonics therefore refers to the way *Kadapa* stone architecture makes material, craft, and structure visibly cohere into built form.

2.3. Cultural Landscape

"Cultural landscapes are the interface between nature and culture, tangible and intangible heritage, biological and cultural diversity—they represent a closely woven net of relationships, the essence of culture and people's identity."

Ken Taylor 2011¹⁴

The concept is vital for this study because it links stone, settlement, memory, and practice into a single historical field. In the Indian context, cultural landscape is not a fixed scenic backdrop, but a living environment shaped by repeated human intervention, social meaning, and long-term continuity. Nalini Thakur notes that Indian built heritage is part of a dynamic cultural fabric and should be understood through the interaction of land, community, and historical time, rather than as isolated monuments.¹⁵ This approach is

useful for *Kadapa* stone architecture because the material itself is tied to quarry zones, transport routes, building traditions, and local settlement patterns.

Thakur argues that Indian cultural landscapes are shaped by regeneration and continuity, where history is renewed through changing use, repair, and reinterpretation rather than only through preservation of an unchanging original.¹⁶ In this sense, the cultural landscape of *Kadapa* stone embodies not only monuments, but also quarries, workshops, roads, water systems, dwellings, temples, and the social practices that connect them. The landscape therefore becomes a record of both material transformation and cultural continuity.

Thakur emphasizes that built heritage as repositories of technical, historical, and geographical information.¹⁷ The concept is useful for explaining how local communities produce and sustain heritage over time.

Kadapa stone architecture can thus be understood as part of a broader cultural landscape in which geology becomes heritage through social practice. The quarry, the mason's yard, the street, the temple, the tank, and the house are interconnected components of one cultural field. The Indian concept of cyclic time expands the understanding of heritage as living rather than static.

3. GEOLOGICAL BACKGROUND

Kadapa stone is a fine-grained sedimentary limestone of the *Cuddapah* System in the Purana rock group, formed between about 1400 and 600 million years ago through erosion, transport, deposition, and lithification. Its mineralogical, textural, and structural properties vary across quarries in Kadapa and adjoining parts of Anantapur and Kurnool districts, depending on depositional conditions, weathering, transport, climate, and broader paleogeography. Its physical behavior and durability are determined by the presence of primarily calcitic, with aragonite and minor authigenic components. It is grey to deep black in color, unified, and highly resistant to wear and water penetration, making it suitable for varied applications.¹⁸



Figure 2: Geological formations of *kadapa* stone such as outcrops and subsurface quarry, stratification, expanse, extant quarry. (Source: Authors).

Geologically, it is stratified into beds separated by bedding planes, which are planes of discontinuity between successive strata (Figure 2). These planes are often arranged roughly parallel to one another, producing concordant bedding with relatively uniform bed thickness. A bed, in this context, refers to the dense stone layer lying between two bedding planes.¹⁹ Although this stratification may be obscure in unweathered rock, it becomes more visible through weathering, and the thickness of quarried stone modules is therefore partly determined by the thickness of the natural beds.²⁰ Geomorphically, *Kadapa* stone occurs in river-bed exposures, hillock-like outcrops, and shallow subsurface deposits, indicating that its extraction potential is closely tied to landform and geological setting. This relationship between geology and quarrying shaped not only the availability of the stone but also the degree of standardization possible in construction units.

4. TECTONICS OF KADAPA STONE

4.1. Extraction Practices, Technological Interventions, and Standardization

Kadapa stone quarrying developed as a historically layered practice in which geology, craft knowledge, and architectural demand together shaped extraction methods and dimensions. Although the early history of quarrying in the region is not fully documented, the continued presence of *Kadapa* stone in structures from at

least the eighth century AD suggests a long and sustained tradition of extraction for building purposes²¹ (Figure 3). Quarrying practices varied according to geological setting. In river-bed sources along Penna and Kundu rivers, where erosion had already removed the overburden, stone blocks could be lifted directly and cut to the required size. Such sources often allowed larger blocks to be removed more easily, particularly when the quarry was located close to the building site, as in the temple remains along the *Penna river* at *Danavulapadu*. In outcrop quarries around *Kolimigundla*, (Figure 3), the stone was exposed on hill slopes or low mounds, while in subsurface quarries, such as those around *Yerraguntla*, *Proddatur*, *Jammalamadugu* and *Chilamkur*, (Figure 1), the workable bed lay below the overburden and extended several meters beneath ground level. These different quarry types shaped both the method of extraction and the dimensions of the stone obtained.

Traditional quarrying was largely manual and labor-intensive, relying on chisels, hammers, crowbars, wedges, and careful knowledge of the rock's natural planes of weakness (Figure 3). They first chiseled holes along joints, fractures, or bedding lines, inserted iron wedges, and struck them repeatedly to split the stone along controlled lines.²² Horizontal splitting followed along bedding planes, after which blocks were levered out. Though slow and physically demanding, this method minimized breakage and maximized usable output. Quarrying was also shaped by environmental conditions: intense heat restricted work to early mornings and evenings, while monsoon rains caused water accumulation in subsurface quarries, often requiring drainage pits to manage water levels. Extraction was therefore not purely technical, but a seasonal negotiation with climate, terrain, and labor (Figure 3).

Standardization existed within this system, though not in the rigid industrial sense. Instead, it operated at multiple levels. Geologically, bedding planes, fractures, and block continuity imposed a natural pre-standardization by determining how stone could be split and sized.²³ And in practice, quarry workers, masons, *sthapathis*, and sculptors developed practical conventions for producing units suited to specific uses such as walls, floors, roofs, and sculptures. Blocks were typically cut with a tolerance of two to three inches on all sides, allowing final adjustments on site. Quarry-level cutting of modules also improved efficiency and reduced waste. This reflects a modular logic based on use, flexibility, and site-specific fit rather than absolute uniformity.



Figure 3: Extraction practices using machines as well as hand tools, stone modules, historic examples of *kadapa* stone construction. (Source: Authors).

Textual traditions further contributed to dimensional order. Architectural treatises such as *Vastu Shastra*²⁴ and *Mayamata*²⁵ prescribed ratios and standards for buildings and sacred structures. These systems were based on human-scale units like *basta* and *angula*,²⁶ and sometimes based on patron-specific measurements. In this way, standardization is a result of geological conditions, craft practices, and textual canons all combined.

Traditionally, stone was moved by bullock cart, as mentioned in the inscriptions of *Porumamilla* temple, which limited its circulation to nearby regions.²⁷ As a result, *Kadapa* stone buildings were concentrated within the district. With the expansion of transport infrastructure such as railways, and lorry network, the material began to move beyond its regional base. Mechanized polishing units further increased their marketability. What has changed is not the existence of standardization, but expanded its scale, speed, and reach.

The colonial and post-independence periods brought further transformation. In the nineteenth century, quarrying remained largely manual, but *Kadapa* limestone began to be used in new infrastructures such as bridges, public buildings, and water systems as a preferred material.²⁸ After independence, quarrying became more regulated under state mineral policies and semi mechanization adhering to the five year plans focusing on industries, significantly increased extraction speed and volume.²⁹ This shift had significantly altered the quarry economy: where earlier practices allowed quarries to operate over long periods with small scale extraction, semi-mechanized methods led to more intensive exploitation, often exhausting quarries within ten to fifteen years and generating at least 10 percent waste of the size of quarry.³⁰

The rise of the cement industry in the *Kamalapuram–Yerraguntla–Jammalamadugu* belt employed open blasting³¹ limestone to meet the increasing demand and extraction pressure. As a result, Kadapa stone transitioned from a locally embedded architectural resource to a commodity within larger industrial and market systems.

Despite these changes, earlier logics of quarrying have not disappeared. Dependence on bedding thickness, rock structure, and traditional splitting techniques continues to shape extraction practices (Figure 3)”. The history of Kadapa stone quarrying is thus best understood as continuity through transformation.

Standardization has always been present, but its form has evolved from a flexible, craft-based and context-sensitive system to one increasingly defined by mechanization, regulation, and market demand, while still retaining traces of traditional know-how.

4.2. Masonry

In the traditional houses of *Uppalapadu* village locally known as *maadi* and *antu middhe*, the wall system can be read as coursed hammer-dressed dry-rubble masonry. The walls are approximately 2 feet thick and 4 to 5 meters high on the ground floor, and about 1.5 feet thick and around 3.5 meters high on the upper floor. Stones are dressed on the exposed face while the rear faces remain irregular (Figure 10). When laid from both sides, these irregular inner faces create voids filled with small stone chips, producing a compact core that reduces continuous vertical joints and transforms the wall into an interlocked structural system rather than a simple stacked assembly.

A distinctive feature is the controlled modulation of coursing. The ground floor alternates between courses of roughly 4 to 4.25 inches and 2 inches, while the upper floor predominantly uses 2-inch courses. In single-storey houses, courses are generally 2 inches thick, with thicker stones at street-facing edges suggesting a deliberate local system of graded coursing. Overall, this standardization likely reflects both quarry bed thickness and guild-based practices, producing a distinctive local masonry expression (Figure 4).

Hammer- or chisel-dressed coursed stone masonry, observed in residences in *Chennur* village and industrial mills in *Proddatur*, represents a more regularized system. Courses are typically about 5 inches high, using lime, mud, or later cement mortar depending on loads, economy and aesthetics. Walls are strengthened with bond stones or through stones, which extend across the full thickness at intervals to tie inner and outer leaves. The wall consists of two roughly parallel stone faces with a mortar-filled core, producing a total thickness of about 1.5 to 2 feet.

Surface finishing varies by material and period: tuck or raised pointing appears in cement mortar, while lime and mud mortar systems use flush or V-grooved joints. The absence of continuous vertical joints, combined with fine mortar joints and regular coursing, enhances stability and allows walls to reach heights of up to 7

meters, as seen in cotton mills. In tectonic terms, it reflects how the cross-section design of a wall affects the scale and structural performance of the overall building.

A third masonry type appears across a 16th-century *Sri Mukti Ramalingeswaraswamy* temple *prakaram* (Figure 4) in *Proddatur* and a 20th-century residence in *Gopavaram*, indicating long continuity.³² Here, stone slabs are placed upright on both wall faces, while the core is filled with random rubble up to slab height. Horizontal through-courses are introduced at intervals to tie both faces together. The system is especially used in lower wall zones, producing a stable base and dense wall that is difficult to break (Figure 4). In the temple context, this resulted in a wall nearly 3 feet thick, structurally capable of supporting superimposed loads of the tapering wall while achieving monumentality through simple, minimally dressed materials.

A fourth type masonry with vertical stone slabs that is commonly used in cattle sheds and differs from plinth-based housing systems (Figure 4). It has no raised foundation; slabs are set directly into the ground to a height of about 6 to 7 feet. After every two slabs, a perpendicular slab is inserted to stabilize alignment, followed by a horizontal tie course of about 1.5 feet thickness at the top. Below this level, construction is largely dry, with occasional metal clamps for reinforcement. Above it, walls continue in dry-stacked *Kadapa* stone scrap, brick masonry, or mud-cob, and are finished with lightweight roofing systems. This is an economical, modular system defined by minimal processing and direct use of available materials.

The Kadapa region is lithologically diverse, with dolomite, quartzite, and other stones occurring in smaller proportions.³³ Kadapa stone was often combined with local materials such as *Mallela Raayi* for ornamentation and cobbles from hillocks or stream beds for dry or coursed masonry, reflecting a sophisticated understanding of properties of micro local materials. This new permutations and combinations produced varied settlement-specific masonry expressions shaped by geology and craft imagination.

Retaining walls formed another major application of *Kadapa* stone, especially in *Kaluva* (canals), *Digudu bavi* (step wells), *Koneru* (sacred temple tanks) and *anakatta* (lake bunds).³⁴ These walls functioned not merely as boundaries but as tectonic devices controlling erosion, seepage, and slope stability while enabling access to water. Kadapa stone's hardness, low porosity, and weather resistance made it ideal for construction in these semi arid regions.³⁵

In historical times, sluice lining and riveting were done with Kadapa stones as identified in *Porumamilla* Tank.³⁶ River embankment at *Danavulapadu* heritage site also relied on stone retaining edges while organizing circulation through steps and platforms. Here, retaining walls were simultaneously structural and ritual, shaping engagement with water.³⁷

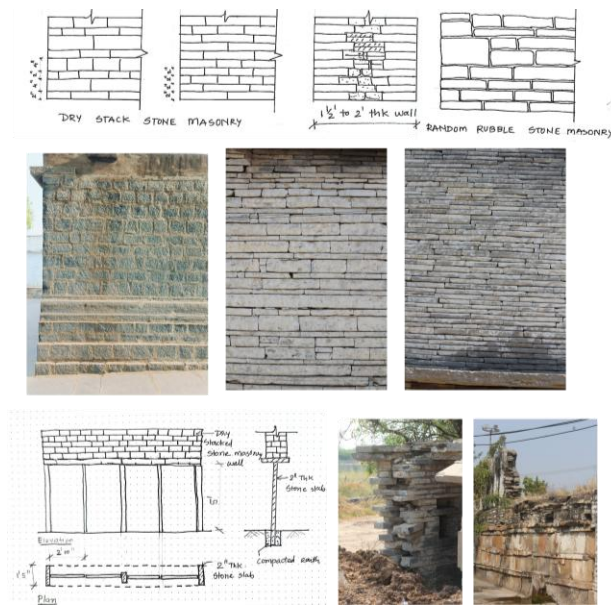


Figure 4: *Kadapa* stone masonry finished with hammer and chiseled dressing. (Source: Authors).

At village scale, retaining walls were integral to commons-based water bodies, shaped by rainfall, seasonal storage, and later canal irrigation, especially after the introduction of the *Kurnool–Cuddapah* Canal, which reorganized regional water distribution.³⁸ During the colonial period, the same material was extended into canal and bridge infrastructure.³⁹ In revetments, *Kadapa* stone continued to perform under flowing water and repeated stress, valued for durability and ease of repair. This continuity shows its adaptation from agrarian and ritual systems into modern engineering regimes.

4.3. Roofing

a. Stone slabs resting on stone beams:

This roof type is predominantly found in *sathrams* (Figure 5), the traditional wayside rest houses of the region. The structure is supported on stone columns composed of three distinct elements like base, shaft, and capital. Rectangular stone beams are laid first in one direction, typically parallel to the walls, and may span up to about 12 feet depending on stone length and structural requirements. Over these beams, stone slabs approximately 2 inches thick are placed perpendicular to the beam direction. Their size is determined by both the center-to-center spacing of the supports and the dimensions of available quarry stone.

The roof is finished either with lime-*surkhi* concrete, about 6 inches thick, using sharp angular *Kadapa* stone chips as aggregate, or with *chowdu middhe*, a clayey-silty material sourced from stream beds and compacted in situ to roughly one foot thickness. This combination of stone slabs and lime finishing enhances thermal performance and water resistance in terrace roofing. Rainwater is typically directed through carved stone

spouts (Figure 5), while roof overhangs are resolved using projecting stone cornices or brackets in flat roofs, and through tabled-joint or dowelled-joint interlocking in inclined roofs.

b. Timber beams and stone slabs on mixed supports:

This roof type is supported on wooden, stone, or composite columns and occurs in two variants. In the first, locally sourced timber poles are laid in both directions. Due to their irregular cross-sections, a bamboo-woven mat is placed above them to create an even base for stone slabs, and the roof is completed with *chowdu* filling, which also improves thermal insulation.

In the second variant (Figure 5), cut and sized timber beams are used in a more regular system, spaced one to two feet apart. Stone slabs are laid directly on the beams and finished with lime-*surkhi* concrete, with edges resolved using stone corbelled projections to protect the wall surface and manage runoff.

c. Metal beams and stone slabs:

During the colonial period, construction practices were reshaped through the selective adaptation of indigenous practices by the PWD engineers.⁴⁰ *Kadapa* stone continued to be used in early colonial buildings, for instance, in corridor roofing of structures such as the CSI Church (1846). However, after the establishment of Basel Mission tile production in 1866, Mangalore tiles became the prescribed roofing material for Public Works Department buildings in the Madras Presidency, leading to the gradual exclusion of *Kadapa* stone from formal colonial roofing systems.⁴¹

Despite this, *Kadapa* stone did not disappear from practice. Broken stone continued to be used as aggregate in *lime-surkhi* concrete in indigenous buildings. Until the early 20th century, residential roofing largely relied on timber rafters. With industrialization and the increased availability of British-manufactured steel, iron and steel supports began to replace timber.⁴² Rolled steel I-sections, being more durable and less susceptible to termite damage, offered a cost-effective alternative.

Structurally, this roofing system closely follows the logic of the timber-beam variant, where cut beams directly support stone slabs (Figure 5). The substitution of steel allowed longer spans and improved structural efficiency while retaining the familiar beam-and-slab construction method. As a result, it came to be regarded as a more permanent, “*pucca*” solution. This roofing type continues to be used in rural areas today, illustrating a technological transition rather than a complete break. Older and newer systems coexisted for a significant period, with some practices persisting while others gradually declined.

d. Corbeled roofing

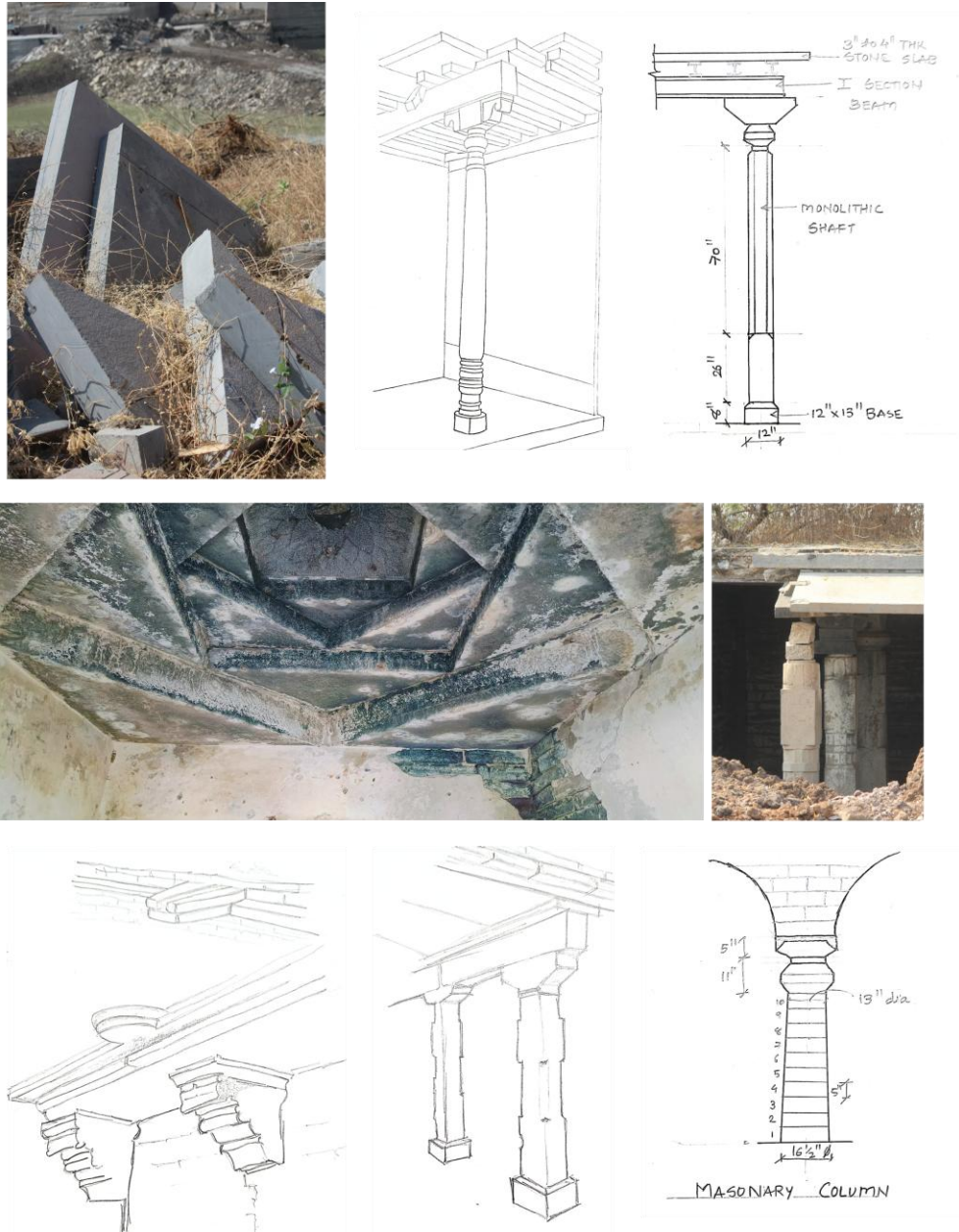


Figure 5: Roofing techniques, support systems, edging and interlocking details, rainwater spouts, adaptation of corbelled roofing from historic times to present. (Source: Authors).

It combines a trabeated structural system with corbelling, most used to cover the *garbhagriha* (sanctum) of modest temples, as seen in historic examples at *Danavulapadu* and *Chilamkur*, as well as in contemporary constructions. The method begins with a square opening, which is gradually closed upward through alternating courses of triangular corner stones and rectangular slabs laid parallel to the beams. With each successive course, the opening reduces in size. During the triangular courses, the plan transforms into a rhombus or inclined square, while the rectangular courses restore it to a square form. This alternating

sequence continues until the opening is sealed by a final square stone at the top, producing a pyramidal, stepped closure through incremental reduction (Figure 5).

This roofing logic is governed both by the geological properties of the stone and by proportional systems derived from architectural treatises such as *Manasara* and *Mayamata*, which prescribe dimensional ratios and spatial relationships for temple construction.⁴³ At the same time, *sthapathis* (sculptors) could adjust ornamentation, and jointing details based on structural needs, availability and local preferences. The fact that these modules continue to be cut at quarries even today reflects the continued transmission of knowledge among quarry workers, masons, sculptors, and *sthapathis* which is shaped by craft-based standardization rather than rigid uniformity.

A recent contemporary example is the JSW Cement *Balaji* Temple at *Bilikalenduru* in *Nandyal*, designed by *Sameep Padora*. The project nonetheless departs from a strictly trabeated system, reinterpreting the roof of the *garbhagriha* through horizontally layered stone slabs placed overload-bearing masonry with slight offsets, producing a gradually tapering stepped profile that rises upward.⁴⁴ This demonstrates how *Kadapa* stone continues to support both traditional construction principles and contemporary architectural reinterpretations.

4.4. Floors and Pavements

Traditionally, *Kadapa* stone was widely used for flooring in both interior and exterior spaces due to its durability and resistance to wear.⁴⁵ It was typically laid as large rough slabs arranged in parallel rows or patterns based on spatial function, and visual intent (Figure 6). The plinth is filled with compacted river sand to create a stable base, followed by a lean lime or cement concrete bed about 4 inches thick. A thin sand layer was then again spread above to adjust irregularities in the underside of the slabs.⁴⁶

Stone slabs, generally 3 to 4 inches thick, were laid over this prepared base, with joints carefully filled and finished to create a continuous surface.⁴⁷ In earlier practice, slabs were often used in their natural state, showing variation in size, thickness, and color, and left relatively rough for utilitarian use (Figure 6). More refined interiors employed better dressed and polished stone.

Polishing was traditionally manual and labor-intensive, involving rubbing one stone against another with sand as an abrasive. Finishes ranged from semi-polished matte surfaces to highly polished, reflective ones.⁴⁸ Module sizes were often standardized, commonly around 1 foot by 1 foot, especially for interior flooring and skirting. Polished *Kadapa* stone was frequently combined with *Bethamcherla* stone from *Kurnool* region, whose

lighter color created visual contrast. This inlay flooring was associated with higher social or economic status, indicating that flooring also functioned as a marker of social distinction.

Colonial regulations such as the MDSS (*Madras Detailed Standard Specifications*) identified *Yerraguntla* in as a primary source of stone to be used for PWD works in the presidency, emphasizing consistency in density, strength, and quality. Stones were required to be free from defects, and typically 3 to 4 inches thick. They are cut into rectangular or square shapes with precise edges. For heavy-duty public areas like Railway stations and industries, slabs of about 25 mm thickness were specified, with strict tolerances of ± 2 mm.⁴⁹



Figure 6: Indigenous techniques of flooring, pavement, and plinth construction. (Source: Authors).

While the bottom face remains rough, the top surface and edges had to be finely dressed, to ensure leveled surface and tight joints often grouted with cement slurry. Flooring required at least seven days of curing, and stones were expected to have low water absorption (below 0.50 percent) to ensure durability against moisture⁵⁰. These standards reflect a high degree of dimensional control and surface precision, although polishing remained manual. Even in contemporary engineering schedule APDSS (Andhra Pradesh Detailed

Standard Specifications) , *Kadapa* stone continues to be recognized as a flooring material, demonstrating its enduring relevance despite changes in construction methods and market demand.⁵¹

As discussed earlier in the paper, the expansion of railway transport in 1866 increased the distribution of polished *Kadapa* stone, especially from *Yerraguntla*, where polishing units were strategically located near railway stations. Later mechanized polishing enabled processing of larger slabs and on both faces, a practice that continues today. Colonial flooring thus combined standardization in size, finish, and jointing with evolving production techniques.

Kadapa stone was also used extensively for paving in traditional settlements where agriculture is the predominant occupation. Slabs were laid on flat surfaces providing necessary inclination to drain surface water, while cobbles were used on slopes, where they provided better traction for pedestrians and bullock carts. Today, many of these stone pavements in streets have been replaced by concrete surfaces to accommodate modern vehicles, indicating a shift in material preference shaped by changing mobility needs.

4.5. Foundations and Plinth

Kadapa stone was widely used in foundations and plinths as they provide strong base for load-bearing walls and while protecting the superstructure from capillary moisture.⁵² Traditionally, it was used in rough foundation masonry, stepped footings, or plinth courses, often combined with lime, mud, or cement.

Plinth height was determined by steps, textual prescriptions, site conditions, and aesthetic considerations. Temple plinths (*pittha* or *adisthana*) were more elaborate, incorporating horizontal bands with recessions and projections such as the *upatala* (base) and *jagathi* (decorated course),⁵³ while still allowing flexibility in execution by the *sthapati*. Larger stone modules were used in such cases, sometimes spanning two to four beds and ranging from 8 to 14 inches in thickness, as seen in temples at *Danavulapadu* and *Anladurthi*.

At *Danavulapadu*, an excavated Jain temple site dating to the 8th-century⁵⁴ period the *adisthana* of a *mandapa-antarala-garbhagriha*⁵⁵ plan survives. The courses vary in height, though stones within each course remain consistent; block lengths differ, with thickness from 12 to 18 inches (Figure 6). The plinth base measures about 40 inches in width, with an additional 5-inch projection for ornamentation. This substantial dimension indicates the scale of the superstructure it supported. In contrast, plinths in other buildings typically range from 2 to 2.5 feet in width. Plinths functioned not only as structural elements but also as key architectural elements expressing scale and proportion.

Column pedestals and footings were constructed similarly, often as pier-like bases in solid or infill masonry, finished with the flooring slab that receives the column base. This links the ground directly to the structural

frame, making the plinth a critical tectonic interface where load transfer, moisture control, and architectural expression converge. In contemporary practice, *Kadapa* stone remains in use for damp-proof courses. Slabs about 2 inches thick are laid in cement mortar at plinth level to prevent rising damp⁵⁶ demonstrating the material's continued relevance in modern load-bearing construction.

4.6. Openings

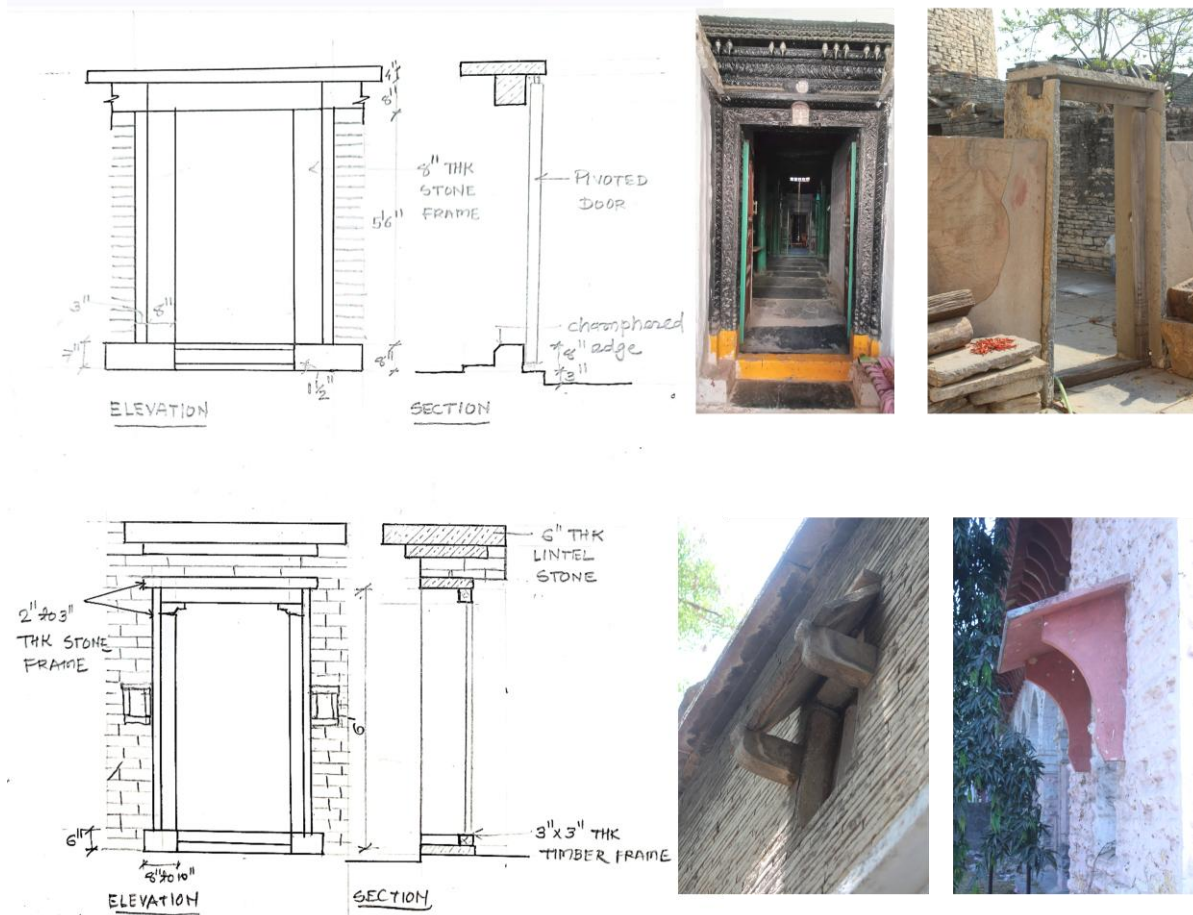


Figure 7: Joinery details of openings, and *chajjas*. (Source: Authors).

Openings in *Kadapa* stone architecture combine structural necessity, material craft, and visual expression. Doors and windows are carefully framed tectonic elements within load-bearing stone walls, with jambs, lintels, sills, and thresholds mediating between wall mass and interior space. Their size and proportion respond to structural capacity, function, climate, and available stone modules, with traditional houses tending toward smaller openings and colonial buildings toward larger, more regular ones. Ventilators are often formed using *Kadapa* stone slabs arranged as louvers or slits. Ornate stone *chajjas* (sunshades), stone pivots,

and simple interlocking butt joints and labelled joints “(Figure 7)” further reveal the craft-based logic of these openings. Textual norms in the *Manasara* also regulate *Simha dwaram* (main door) proportions. Highly ornate lintels, sometimes combined with wood in residences in *Chennur*, indicate the social and symbolic significance of openings.

4.7. Staircases

Kadapa stone stair construction appears in multiple forms, each responding to distinct spatial, functional, and social conditions. In modest single-storey houses, exterior staircases are commonly built using 3-inch-thick stone slabs cantilevered from the wall, either as floating steps or as tread-riser units (Figure 8). These stairs usually serve as service access and are arranged in a single flight, with relatively high risers compared to other types. Their exposed placement and simple structural logic demonstrate the economical and direct use of stone in everyday domestic construction.

A second type follows a hybrid system found in traditional residences, where staircases are constructed using masonry cores finished with stone slabs (Figure 8). Because each step is formed over a masonry base rather than a single monolithic block, slight variations in rise are common. These staircases appear as single-flight or L-shaped forms and are typically located in front yards, backyards, or internal circulation zones.

A third and more specialized form is the stone spiral staircase found in temples and *Maadi illu* (houses more than single story). Here, monolithic stone steps, carefully cut and dressed, are cantilevered from the wall and arranged around a central core (Figure 8). Each step overlaps slightly with the one below, producing a precise and continuous spiral geometry. These staircases may extend across two to four storeys, as seen in the house at *Ramanapalli* and the *Sri Kanyakaparameshwari* Temple, *Proddatur*, both over a century old⁵⁷ and significant landmarks. In the latter, the spiral staircase tower (Figure 8) is considered the tallest extant stone structure built in *Kadapa* stone, demonstrating a strong relationship between structural precision and architectural ingenuity.

A fourth type is the U-shaped open-well staircase in the old Collectorate building, *Kadapa* (Figure 8), a major colonial-era structure built in 1889. This building reflects an eclectic hybrid style combining Islamic and Victorian architectural influences with local construction practices.⁵⁸ The staircases at both corners are cantilevered using single stone slabs approximately 6 inches thick, projecting about 3 feet 6 inches from the wall, with tread depths ranging from 12 to 21 inches and overlaps of 3 to 4 inches. The width of stairs can accommodate two to three users simultaneously, reflecting its administrative function as opposed to single user stairs in Indigenous buildings.



Figure 8: Structural innovations. (Source: Authors).

Collectively, these staircase types demonstrate how *Kadapa* stone was adapted across domestic, religious, and administrative contexts through varied tectonic systems. The staircase thus becomes an indicator of function, hierarchy, and evolving construction practices, showing that standardization in *Kadapa* stone was rooted not in industrial uniformity but in craft-based dimensional control and local building knowledge.

4.8. Arches

Arches in the built fabric of this region appear as a relatively later development, becoming more common from the period of *Islamic* influence onward. In traditional residences, they were primarily structural elements used to span openings and support loads above. In villages such as *Chennur*, arches form a distinctive feature of façades (Figure 9) and shape the residential architectural character, spanning approximately 0.6 to 2 meters.

The most common arch type in traditional contexts is the semicircular arch, typically constructed with a keystone and symmetrical voussoirs. This reflects a clear tectonic logic in which geometry is closely tied to load transfer as well as visual articulation. In such buildings, the arch functions simultaneously as a structural and stylistic device, shaping façades while resolving wall openings in stone construction.

In colonial buildings, multiple forms are present, including segmental arches, pointed arches (such as lancets), trifoliated arches that are carved or chamfered, and semicircular arches for larger spans. In the Collectorate building, arches are used more extensively to support roof spans of up to 4 meters. In both traditional and colonial buildings, the voussoirs are not always perfectly uniform; instead, they are often dressed in the same

manner as the adjoining masonry (Figure 9). This indicates that *Kadapa* stone arch construction relies less on rigid modular precision and more on craft-based adjustment and local workmanship on site.



Figure 9: Expanding the possibilities of Arch construction logic beyond mere aesthetic expression. (Source: Authors).

Unlike traditional buildings, colonial residences in the region generally do not employ arches, suggesting that the form became more associated with institutional and public architecture rather than domestic use. Over time, arch construction has largely disappeared in contemporary building practice due to the shift toward framed structural systems and the labor-intensive nature of stone arch construction. Its discontinuity thus reflects both a change in structural systems and a decline in the skilled labor required for stone masonry traditions.

4.9. Reuse practices

Once quarries are exhausted, the same clay and silt layers in bedding planes and laminae, which settle at the base level, act as an impervious layer that retains water and eventually forms water bodies.⁵⁹ Traditionally, stone chips were reused in lime-*surkhi* concrete, and stone scrap was incorporated into new construction, especially from dry masonry, since lime mortar joints harden over time and make the wall more monolithic. Stone chips were also used in the preparation of quicklime in local lime kilns. In contemporary practice, reuse

continues in cost-effective construction, including paving methods like brick-on-edge patterns, fencing and boundary walls for agricultural fields and modest residences, and dry-stone scrap stacking in plinth construction.

Stone scrap, usually of irregularly cut sizes, is widely used in an informal dry-rubble masonry tradition, typically found in modest houses near quarry zones. These are treated as low-cost or formerly free material, construction with these sizes does not require fine dressing or highly skilled workmanship. Stones with machine cut faces are placed on the outer wall surfaces, while larger irregular pieces are packed into the core. Construction is usually limited to low-height walls of about 3 meters and single-storey structures with lightweight roofs, reflecting how reuse is embedded in everyday construction practice rather than functioning as a distinct sustainability strategy.



Figure 10: Exemplars of material - culture continuity (Source: Authors)

5. CONCLUSION

Kadapa stone architecture reveals a long continuity of material practice shaped by geology, craft knowledge, and changing construction cultures. From quarrying and stone selection to masonry, roofing, flooring, plinths, openings, staircases, arches, and reuse, the material has been worked through a range of tectonic systems that respond to local conditions and building needs. Across these examples, *Kadapa* stone emerges not simply as a construction material but as an architectural medium through which structural logic, environmental adaptation, and cultural meaning are made visible.

A central finding of this study is that standardization. In traditional contexts, it emerged through bedding thickness, quarry-based splitting, craft conventions, textual proportional systems, and site-specific adjustment. Quarry workers, masons, and sculptors who embody the knowledge often the decision makers and shaped architecture of the region often allowing variation within an overall logic of building construction practices. Colonial construction introduced a different mode of standardization, one organized through drawings, specifications, and more clearly defined roles between engineer, builder, and laborer. Here, the stone artisan is a mere executor of work as per the instructions given. Yet even here, the material was not reduced to abstraction: *Kadapa* stone continued to be shaped by its physical properties, and many colonial buildings still depended on local workmanship and adaptation on site.

The contrast between traditional and colonial construction therefore lies less in the material itself than in the social organization of building. Traditional architecture reflects a mass-based, craft-led system in which decisions are negotiated on site and stone is worked according to availability, skill, and immediate need. Colonial architecture, by contrast, reflects a compositional and hierarchical system in which elements are more fully defined in advance, repeated across projects, and controlled through formal procedures. At the same time, both systems relied on the same material intelligence: *Kadapa* stone's durability, thermal mass, workability, and resistance to water made it suitable for houses, temples, water structures, public buildings, and infrastructure across different historical periods.

The study also shows a decline in residential construction is not caused by scarcity alone, but by changing aspirations, faster construction systems, labor shortages, and altered economic and aesthetic preferences. Even so, the material has not disappeared. It continues to survive in selective applications, in contemporary reinterpretations, in reuse practices, and in buildings that still value its performance and symbolic value. In this sense, *Kadapa* stone architecture demonstrates continuity through transformation: traditions persist not as fixed inheritances, but as practices repeatedly translated into new conditions (Figure 10). The material history of *Kadapa* stone therefore offers a way to understand the cultural landscape of the region as a reflection of Architectural and Technological Knowledge Systems in which geology, craft, technology, and social change remain closely intertwined.

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Traditional Dwellings and Settlements

Working Paper Series

THE WHISPER OF THE SAW: UNEARTHING THE SECRETS OF TACGUSASTRA, THE INDIGENOUS KNOWLEDGE IN KERALA'S TRADITIONAL TEMPLE ARCHITECTURE

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THE WHISPER OF THE SAW: UNEARTHING THE SECRETS OF TACHUSASTRA, THE INDIGENOUS KNOWLEDGE IN KERALA'S TRADITIONAL TEMPLE ARCHITECTURE



Tachusastra is a traditional science of carpentry, that is indigenous to the State of Kerala in India and much more than just building with wood. It's a comprehensive system that combines cosmic science, spirituality, mathematics, and aesthetics to create structures in wood that are in harmony with nature. Practitioners, known as Tachans or Asharis, used these ancient principles to design and construct everything from grand temples to simple homes, all while following the specific set of rules. Tachusastra represents a profound indigenous knowledge system that transcends conventional understanding of carpentry, embodying a sophisticated confluence of mathematical precision, environmental wisdom, and sacred scientific principles. Drawing from Sanskrit texts, oral traditions, archaeological evidence, and living practices, the objective of the research paper is to illuminate how carpentry in Kerala, transcended mere craftsmanship to become an integrated indigenous knowledge system encompassing material knowledge, structural engineering, aesthetics, and spiritual symbolism. The paper focusses on exploring the complex mathematical framework underlying Tachusastra, particularly focusing on its unique system of proportional measurements (angulam), geometric principles (rekha), and structural calculations (manam) and also to examine Tachusastra's sustainable practices, particularly its sophisticated understanding of local materials, environmental conditions, and ecological balance. This analyzes how indigenous joinery systems can meet current structural engineering standards, how traditional wooden architecture offers sustainable alternatives to energy-intensive modern construction, and how the philosophical underpinnings of Tachusastra align with emerging approaches to biophilic design. The methodology adopted is documentation of existing indigenous timber buildings and using content analysis to rediscover the sophisticated understanding of wood properties, joinery techniques, and architectural applications developed by the indigenous master craftsmen across diverse regional traditions. Detailed technical illustrations, material science analyses, and step-by-step methodologies bridge the gap between ancient wisdom and contemporary implementation.

This research paper brings out the rich tradition of Tachusastra, the ancient Indian science of carpentry, offering a comprehensive examination of techniques, philosophies, and applications that have evolved over millennia across the Indian subcontinent. The paper reveals how these methods addressed the climatic conditions and cultural requirements of the region while maintaining core principles of sustainability and harmony with natural elements. Beyond historical documentation, this work establishes the contemporary relevance of traditional carpentry knowledge in addressing modern challenges. Definitely, the past has power; tradition and traditional knowledge have been found ecologically viable, economically feasible and socially desirable. We must be able to interpret the traces left by the tools of our ancestors on the existing buildings and elevate them to today's scientific realm. The search into the construction methods and practices followed in traditional buildings of Kerala is about the description and analysis of processes, not 'stationary' buildings. Such knowledge can only partly be verbalized, as it is transmitted or transferred through actual work. The findings though, bring out local construction methods and techniques which are to be used in the conservation of traditional timber buildings of Kerala, are definitely hinting at globally applicable general ways of thinking that traditional methods and practices of construction are quite sustainable.

1. INTRODUCTION

Traditional knowledge systems have played a pivotal role in shaping the architectural and engineering heritage of various civilizations. In India, the science of carpentry has been deeply rooted in indigenous wisdom, with regional variations reflecting unique ecological, cultural, and philosophical influences. One such highly developed system is Tachusastra, the traditional science of carpentry in Kerala, which embodies a sophisticated understanding of material selection, structural design, and craftsmanship. *Tachusastra* is a highly refined system of architectural knowledge that integrates principles of geometry, material science, and

structural engineering, deeply rooted in Vedic traditions. It governs the construction of temples, palaces, and vernacular homes, emphasizing precision, durability, and harmony with nature while reflecting Kerala's unique climatic and cultural context. This research paper presents a comprehensive analysis of Tachusastra, the traditional carpentry science of Kerala, examining its intricate integration of mathematical principles, sustainable practices, and sacred sciences. This paper aims to decode the principles, methodologies, and applications of Tachusastra, analyzing its relevance in contemporary architectural practices. By exploring historical texts, case studies, and expert insights, this research seeks to bridge the gap between traditional wisdom and modern construction techniques, emphasizing the potential of Tachusastra in fostering sustainable and ecologically responsive architecture.

Through detailed study of primary sources, including ancient manuscripts, oral traditions of master carpenter (Perumtaccan) families, and extant architectural examples, this research demonstrates how Tachusastra represents a sophisticated indigenous technical knowledge system that transcends mere craftsmanship. The objectives of the paper are to explore the complex mathematical framework underlying Tachusastra, particularly focusing on its unique system of proportional measurements (*angulam*), geometric principles (*rekha*), and structural calculations (*mānam*) and also to examine Tachusastra's sustainable practices, particularly its sophisticated understanding of local materials, environmental conditions, and ecological balance. The research adopts a comprehensive and multidisciplinary approach to decode its principles in the context of sustainability, mathematical precision, and sacred science. Given its deep-rooted significance in both practical and philosophical domains, this research paper employs a combination of textual analysis, field studies, and expert consultations to systematically unravel its underlying principles. A significant portion of the research documents how traditional carpenters select, season, and utilize different wood species based on their structural properties, durability, and local availability. The paper reveals how traditional design principles naturally incorporate climate-responsive features, including natural ventilation, solar orientation, and rainfall management, offering valuable insights for contemporary sustainable architecture. The paper concludes with recommendations for incorporating Tachusastra's principles into contemporary architectural education and practice, suggesting frameworks for bridging traditional wisdom with modern technological advances. This research has important implications for sustainable architecture, cultural heritage preservation, and the revival of indigenous knowledge systems in contemporary contexts.

Tachusastra is more than a set of construction techniques; it is an intricate blend of geometry, physics, and aesthetics, governed by principles derived from Vedic traditions and adapted to the specific environmental and socio-cultural context of Kerala. The meticulous guidelines prescribed in Tachusastra have been instrumental in the construction of temples, palaces, and traditional homes (*nalukettu*), ensuring durability, climatic adaptability, and spiritual harmony. However, despite its historical significance, this indigenous

science is gradually fading due to modernization, lack of documentation, and the decline of traditional apprenticeship systems.

2. THEORETICAL REVIEW OF EXISTING LITERATURE

This literature review examines academic sources on Tachusastra's mathematical frameworks and sustainable practices, organized thematically to address the research objectives. The traditional carpentry science of Kerala, known as *Tachusastra*, has garnered increasing scholarly attention as a sophisticated indigenous knowledge system that integrates mathematical precision, sustainable practices, and cultural significance. This literature review examines the existing scholarship on *Tachusastra*, identifying key themes, methodological approaches, and gaps in the current understanding of this ancient architectural tradition. The review situates *Tachusastra* within broader discourses on traditional knowledge systems, sustainable architecture, and the integration of indigenous practices into contemporary design frameworks. "Tachu" refers to carpentry, while "Sastra" denotes science. In Malayalam, a carpenter is known as a "Tachan." The title "Perumtachan," meaning Master Carpenter, represents the highest authority in Tachusastra, the traditional science of carpentry and architecture.

Scholars have increasingly recognized the importance of traditional knowledge systems in architecture and construction Tom B (2007). Varma (2019) argues that traditional architectural practices like *Tachusastra* represent comprehensive epistemological frameworks rather than merely technical skills. This perspective is supported by Varma (2020), who demonstrates how *Tachusastra* embodies a holistic understanding of material properties, environmental conditions, and cultural values. The documentation of traditional architectural practices has been a significant scholarly focus. Menon (2018) provides a comprehensive ethnographic study of *perumtaccchan* (master carpenter) families in Kerala, highlighting the oral transmission of knowledge and the social structures that maintain these traditions. This also examines the ritualistic aspects of *Tachusastra*, demonstrating how technical knowledge is embedded within sacred practices and belief systems. The mathematical sophistication of *Tachusastra* has been a central focus of recent scholarship. Balakrishnan (2021) analyzes the complex proportional system of *angulam* (finger measurements) used in *Tachusastra*, demonstrating its relationship to anthropometric scales and cosmic orders. This work builds on earlier studies by Chandra (2018), who identified the geometric principles (*rekha*) that govern spatial organization in traditional Kerala architecture. The structural calculations (*mānam*) employed in *Tachusastra* have been examined by Pillai (2020), who demonstrates how these principles facilitate the creation of stable structures without modern engineering tools. Further research reveals how these calculations incorporate considerations of material properties, environmental factors, and anticipated loads, suggesting a sophisticated understanding of structural mechanics.

The ecological wisdom embedded in *Tachusastra* as detailed by Tom B (2007), has brought out significant scholarly findings including its natural dependence. His research documents how traditional Kerala architecture incorporates climate-responsive features, including natural ventilation systems, optimal solar orientation, and effective rainfall management. These findings are complemented by further researches in the field which analyze the thermal performance of traditional buildings constructed according to *Tachusastra* principles. Recent research has moved beyond viewing *Tachusastra* solely as a traditional carpentry system and increasingly recognizes it as a sophisticated body of knowledge encompassing material science, ecological management, sustainable design, and educational relevance. Studies on timber selection and resource use have revealed that traditional practitioners possessed a highly nuanced understanding of wood species, durability, grain behavior, environmental suitability, and lifecycle performance. This research shows that timber was not chosen merely for availability but through informed systems that considered structural function, resistance to decay, and long-term sustainability. Further investigations into resource management have also demonstrated that *Tachusastra* was closely aligned with environmentally responsible harvesting practices, including regulated timber use, ecological sensitivity, and forms of forest stewardship that supported biodiversity and conservation. More recent scholarship has expanded this discourse by exploring how *Tachusastra* can inform contemporary architecture. Researchers have begun examining ways in which traditional proportional systems, spatial logic, and climate-responsive strategies can be adapted into modern design frameworks, particularly within sustainable and regenerative architecture. Case-based studies suggest that several contemporary projects successfully integrate principles such as proportional harmony, passive environmental control, and local material intelligence derived from *Tachusastra*. At the same time, scholars in architectural pedagogy increasingly argue that traditional knowledge systems should play a larger role in design education, not as nostalgic heritage but as valuable intellectual resources capable of addressing current ecological and technological challenges. This growing body of work positions *Tachusastra* as a potentially significant framework for future design innovation. Despite this expanding interest, substantial gaps remain. Technical documentation of many traditional practices is still fragmented, and regional differences within Kerala's carpentry traditions have not been comprehensively studied. Historical transformations, localized adaptations, and the evolution of specific construction techniques require deeper investigation. Comparative studies with other indigenous architectural systems—both within India and globally could further illuminate broader patterns of environmental adaptation and craft intelligence. Moreover, while theoretical discussions often highlight the contemporary potential of *Tachusastra*, there is still limited empirical research measuring how these principles perform when applied to present-day architectural contexts. Questions surrounding structural performance, environmental efficiency, cultural integration, and social acceptance remain underexplored. Future scholarship must therefore move toward more rigorous interdisciplinary inquiry that combines

historical research, technical analysis, and applied experimentation to fully understand the enduring relevance of Tachusastra.

2.1. Research Method

Traditional Knowledge, in Timber Architecture, means a particular knowledge of timber construction that has been used over a period of time and is rooted in the past local or regional architectural activity. Timber is a natural material extracted directly from nature and is processed or seasoned, and finished on the building site by the craftsmen. Their knowledge of the properties of the material was based on the experience inherited from the previous generations and is indeed a strong database. The strength of this knowledge, used in the processing of traditional building materials and construction, lies in the fact that it has been tested over centuries, providing a sufficient guarantee of its reliability and durability. This research employs a mixed-methods approach combining historical analysis, ethnographic fieldwork, and comparative case studies. The study is primarily qualitative and observational in nature, utilizing archival research, field observations, and practitioner interviews to develop a comprehensive understanding of Tachusastra principles and applications. The research design incorporates both diachronic elements, tracing the historical development of Tachusastra traditions, and synchronic analysis examining contemporary applications and adaptations. The data collection methods used are archival research sourcing from primary text “Manushyalaya Chandrika”, ethnographic field work, semi structured interviews of 4 master carpenters of age 80 and above, detailed measured drawings, photographic documentation and analysis historical buildings including temples and palaces built between 15th and 18th centuries. Field observation sheets utilizing standardized notation system were used throughout the research. Cultural protocols such as recognition of sacred aspects of architectural knowledge and respect for community restrictions on documentation of certain ritual elements were observed during the research. The researcher maintains a commitment to knowledge reciprocity through educational workshops and documentation sharing for academic purposes.

2.2. Analysis and results

2.2.1 The architectural acumen

The architectural landscape of this region was predominantly defined by wooden structures, with timber serving as the primary building material for both religious and domestic buildings. Stone—specifically granite and laterite—was used sparingly, typically confined to plinths and select wall sections. Spanning buildings constructed between one to five centuries ago, this architectural tradition is distinguished by exceptional woodworking skills and extraordinary craftsmanship that epitomizes the southern regional style. These wooden edifices are not merely functional but are adorned with intricate, purposeful ornamentation that

reflects deep cultural sophistication. Religion profoundly influenced every aspect of architectural design and construction. From selecting the building site to determining measurement systems, from choosing the commencement date to orienting the structure, religious beliefs played a pivotal role. Builders meticulously adhered to complex architectural canons, believing that any deviation could potentially anger the divine and bring misfortune to the inhabitants. These architectural guidelines, developed through centuries of accumulated building expertise, were so refined that they essentially created a "genetic code" for timber architecture. Precise formulae governed proportions, dimensions, location, and construction procedures, ensuring a remarkable consistency and spiritual integrity in each structure. The result was an architectural tradition that was simultaneously practical, artistic, and deeply spiritual a testament to the intricate relationship between built environment, cultural beliefs, and religious practice.

The science of architecture (Vastusastra) according to Vedic principles was widely accepted all over the Hindu regions in regional versions like Tachusastra (traditional science of carpentry (Taccu)), which was scrupulously followed in Travancore. This science of timber craft is synonymous with the traditional science of architecture. Strict adherence to the principles laid out by Tachusastra resulted in the creation of not only a well-defined style, but also produced buildings that were pleasingly proportioned and appropriate to the human scale, as well as being in complete harmony with nature and thence attaining for themselves longer life span. The craftsmen, who were highly skilled, made creative and innovative use of wood within the severe constraints of the rules of building science. A traditional building of Travancore, visually, makes a dramatic vertical statement with its dominant, steeply sloping roof and hence the ultimate test of the craftsman's skill was laid in assembling the roof frame. The highest skills were obviously that of the carpenter or Tachan, and consequently the science of Vasthu was called as Tachusastra in this region.

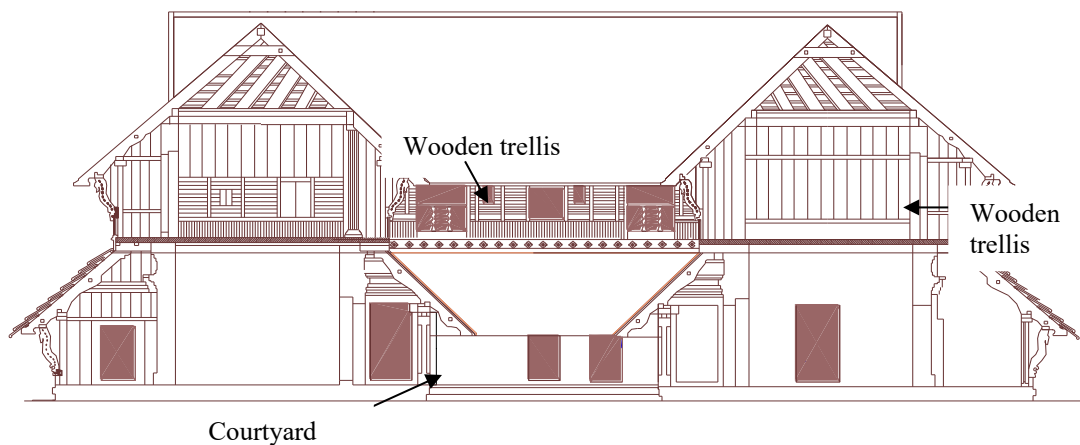


Figure 1: Section of Thai Kottaram (Padmanabhapuram palace) through the courtyard. (Source: Author).

The research reveals that Tachusastra represents a sophisticated indigenous knowledge system with standardized design principles manifested through modular geometry, precise dimensioning, and proportional systems. The traditional dimensional framework operated through both proportional (Anupadhikam) and absolute (Kevalam) systems, with the octal measurement system (Angulamanam) serving as the primary matrix for architectural proportioning. This system established the uthamangulam (30mm) as the basic unit, with 24 angulams forming one kol (720mm), creating a standardized framework for consistent construction across the region.

The analysis of architectural planning demonstrates that traditional Kerala structures followed the cosmic man (Vastupurusha) concept, with buildings configured as modular assemblages around courtyards (ankana). The basic unit (shala) evolved into more complex forms such as chathurshala (four-unit structures) that characterized the palaces (Kottaram) of Travancore. The research identified that traditional buildings were conceptualized as living entities with six distinct limbs analogous to the human body: paduka (foundation), jangha (walls/pillars), uru (cornice beam), vapus (upper wall), siras (roof), and sthupika (pinnacle), each constructed with precise proportional relationships.

2.2.2 Mathematical precision in Kerala's traditional roof timber framing

The traditional roof system of Kerala represents a remarkable confluence of mathematical precision, architectural ingenuity, and structural engineering principles. Drawing from the ancient text *Manusyalaya chandrikabhasyam*, the roof construction relies on sophisticated geometric calculations and proportional systems that demonstrate an advanced understanding of structural mechanics. The roof design process begins with a systematic geometric approach. Carpenters utilize a fundamental technique of drawing right-angled triangles on a flat plank (pramanaphalaka) typically at a 1:8 scale to represent half the roof frame. This method allows precise calculation of rafter lengths by establishing the base as half the span of the house, the altitude as the rise of the roof above the wall plate, and the hypotenuse representing the straight rafter length. The spacing of rafters follows intricate mathematical rules that showcase remarkable precision. Carpenters subtract 1 from twice the number of slanting rafters and divide the remaining number into carefully calculated spacing intervals. This process involves allocating 2 parts between slanting rafters and adding 1 part at the center of the house width. Rafter dimensions are equally meticulously determined, with width varying from the wall plate width to 2-1.5 times that measurement, and thickness ranging from 1 to 6 angula (traditional measurement unit).

Key structural elements like Uttara (wall plate) and ridge (vamsa) are dimensioned using proportional relationships that reflect a deep understanding of structural integrity. The ridge width and length can be $\frac{3}{4}$ of the wall plate width or alternatively 6-7 angula square. Joint connections are calculated using 3-4 times the

rafter thickness, ensuring maximum structural stability. Remarkably, these calculations are not purely functional but also incorporate aesthetic considerations. Supporting struts are prescribed to be carved with intricate sinusoidal motifs, creepers, and floral designs, demonstrating an elegant integration of structural engineering and artistic expression. The calculations provide a framework with extraordinary flexibility, allowing eave projections to be calculated in six different ways and enabling adaptations based on specific architectural requirements.

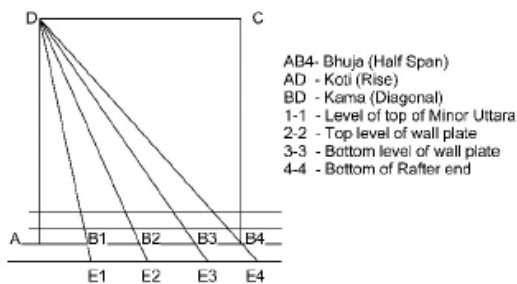


Figure 2: Method to calculate length of rafters. (Source: Shikarvidhaya, Manusyalayachandrikabharyam - An engineering commentary on traditional Kerala architectural practices).

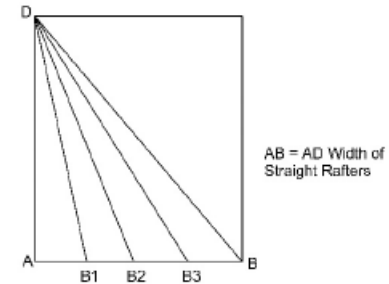


Figure 3: Method to calculate width of rafters (Source: Shikarvidhaya, Manusyalayachandrikabharyam - An engineering commentary on traditional Kerala architectural practices).

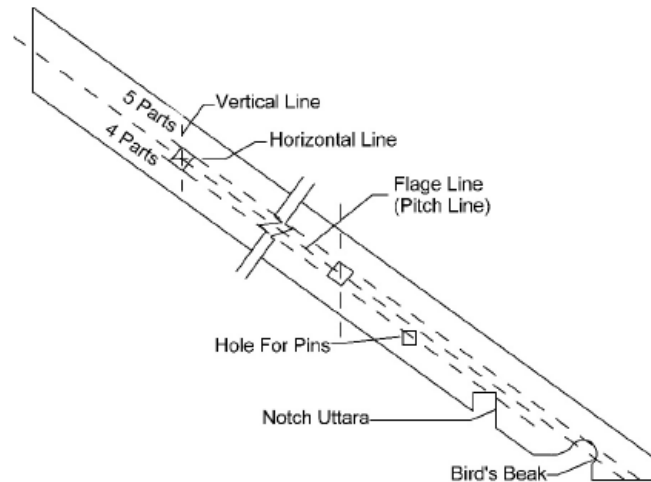


Figure 4: Marking reference line of Rafter. (Source: Shikarvidhaya, Manusyalayachandrikabharyam - An engineering commentary on traditional Kerala architectural practices).

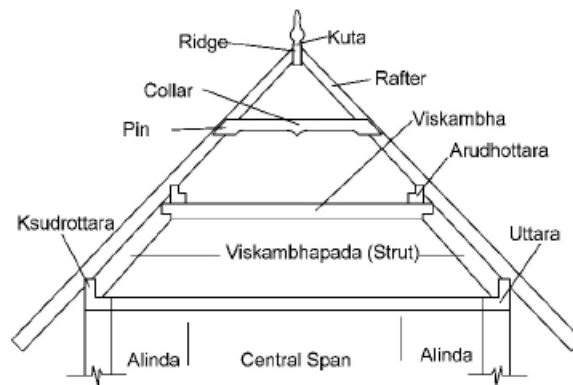


Figure 5: Components of the roof structure. (Source: Shikarvidhaya, Manusyalayachandrikabharyam - An engineering commentary on traditional Kerala architectural practices).

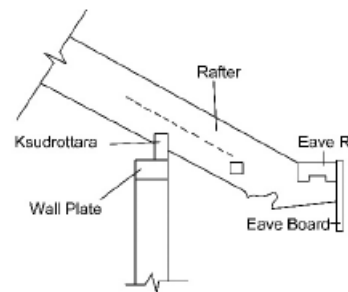


Figure 6: Details at Eave. (Source: Shikarvidhaya, Manusyalayachandrikabharyam - An engineering commentary on traditional Kerala architectural practices).

This mathematical approach reveals that Kerala's traditional carpentry (Figure 7) was far more than a mere craft—it was a sophisticated science. The roof system demonstrates an extraordinary understanding of geometry, structural mechanics, and proportional design that predates modern engineering principles by centuries. Each calculation, each proportion, and each decorative element speaks to a profound knowledge of architectural engineering that balanced functional requirements with aesthetic sensibilities. The precision of these traditional methods is particularly impressive when one considers the limited technological tools available at the time. Carpenters relied on intricate knowledge passed through generations, mathematical understanding, and an intimate relationship with natural materials. The roof system becomes a testament to the intellectual and technical sophistication of traditional Indian architectural practices, particularly those of Kerala. The study documents the sophisticated timber joinery methods employed in traditional construction, primarily using mortise and tenon variations with specific classifications for vertical connections (*Mesayuddha*, *Trikehandaka*, *Saubhadra*, *Ardhapani*, and *Mahavrittha*) and horizontal connections (*Shathsikha*, *Sukaraghrana*, *Vajrasannibha*, *Nandhyavartha*, and *Sarvathobhadhra*). This prefabricated "construction kit" approach enabled structures to resist decay in Kerala's humid climate while facilitating ease of assembly.

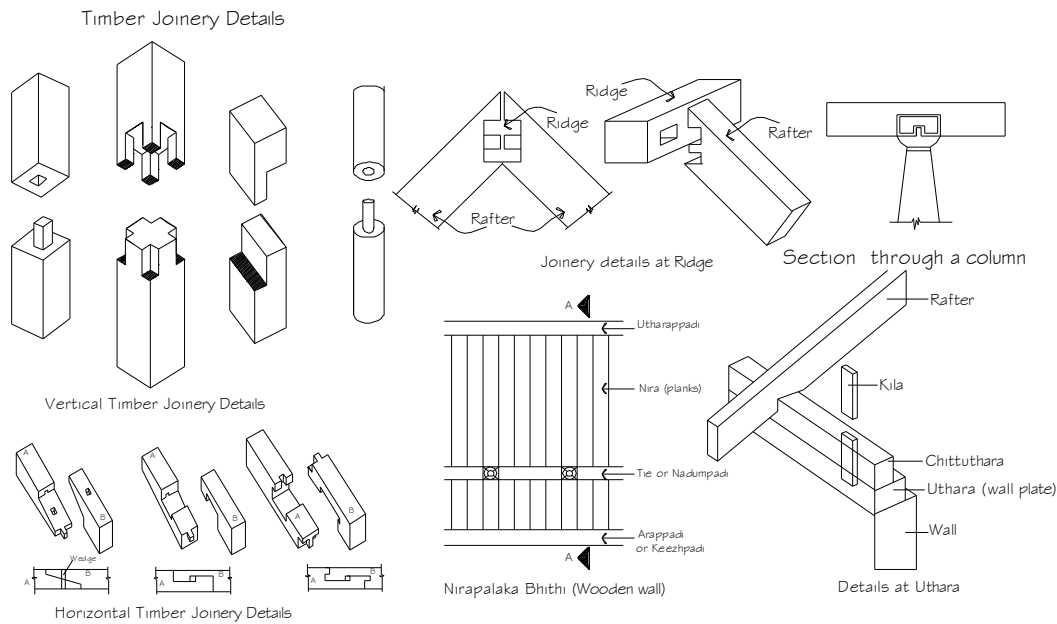


Figure 7: Traditional carpentry joineries. (Source: Author).

The woodwork joints demonstrate the carpenters understanding of the material. Though the whole structure consists of prefabricated members, assembled later at the time of erection, none of the joinery details are visible. The assemblages were either vertical joints or horizontal joints. A closer look reveals many of the complex joinery systems such as, *arukuduma* (mortise and tenon, with 6 tenons and corresponding mortises), which was a joint developed by the carpenters of Travancore. These traditional practices, transmitted through the master-disciple (*gurusishya parampara*) system within carpenter (*taccan*) guilds, represent a valuable architectural heritage that incorporated cultural influences over centuries while maintaining core structural principles. The research concludes that the traditional knowledge system embedded in Tachusastra provided effective mechanisms for moisture management in timber structures, explaining their remarkable longevity despite challenging climatic conditions.

2.2.3 Tachusastra as indigenous epistemological framework: Integrating carpentry, geometry, proportion, ritual science, and environmental adaptation

Tachusastra, within Kerala's architectural tradition, must be understood not merely as a technical manual of carpentry but as a sophisticated indigenous epistemological framework—a structured system of knowledge through which building practices mediated relationships between material, environment, body, society, and cosmos. Its significance lies in the fact that carpentry was never isolated as a mechanical act of construction; rather, it operated as an interdisciplinary science combining geometry, proportion, ritual order, ecological

intelligence, and hereditary craft practice. In this sense, Tachusastra constituted a localized architectural philosophy where making was inseparable from knowing, and building was simultaneously a technological, cultural, and metaphysical process.

At its core, Tachusastra was rooted in embodied carpentry knowledge transmitted through hereditary Tachan communities, whose expertise extended beyond woodworking into material science, environmental strategy, and sacred procedure. The carpenter functioned as craftsman, engineer, mathematician, and ritual specialist, demonstrating that indigenous knowledge systems in Kerala did not divide theory from practice in the manner of modern disciplinary structures. Skills such as species-specific timber selection, lunar-cycle harvesting, seasoning, moisture control, joinery, and preservative applications like *ettukoottu* reveal that practical carpentry was embedded within broader systems of biological observation, climatic responsiveness, and cyclical maintenance. This craft knowledge, refined through oral transmission and empirical continuity, represents an epistemology grounded in lived practice and ecological adaptation.

Geometry and proportion formed the intellectual scaffolding of this system. Through the interrelated principles of *angulam*, *mānam*, and *rekha*, Tachusastra encoded architecture within measurable frameworks that regulated dimensional precision, structural coherence, and symbolic order. Geometry was not an abstract mathematical exercise but a practical and cosmological instrument. *Angulam* established anthropometric scale; *mānam* organized proportional relationships among structural elements; and *rekha* translated these into spatial geometry and layout logic. Such systems ensured that architecture responded simultaneously to human ergonomics, structural necessity, and sacred alignment. In Kerala's timber buildings, these mathematical systems are visible not only in formal order but in environmental details such as roof pitches, courtyard dimensions, drainage gradients, and joinery calibration. Thus, proportion served as a bridge between technical performance and philosophical meaning.

Ritual science further distinguishes Tachusastra as an epistemological system rather than a purely technical craft. Construction practices were embedded within broader Vastuvidya and Tantric frameworks, where orientation, sequencing, consecration, and material use were governed by sacred codes. Building was perceived as an act of harmonizing human habitation with cosmic order. Texts such as *Tantrasamuccaya* and *Manuśyālaya Chandrika* indicate that architecture was shaped by ritualized procedures that linked site, direction, proportion, and occupation to spiritual equilibrium. This cosmological dimension did not oppose scientific rationality; rather, it expanded it by situating technical acts within ethical and metaphysical systems. Lunar timber harvesting, auspicious measurements, and ritual consecration reveal that material processes were informed by an integrated worldview in which celestial cycles, environmental conditions, and sacred practice intersected.

Equally central to Tachusastra is its environmental epistemology. Kerala's monsoon climate demanded architecture capable of managing moisture, heat, rainfall, and biological decay. Traditional timber architecture responded through preventive intelligence: granite plinths acted as moisture barriers; trelliswork functioned as passive ventilation systems; jwala projections and overhangs mitigated rain penetration; and modular timber joinery enabled structural resilience and repairability. These features demonstrate that environmental adaptation was not supplementary but foundational to the knowledge system itself. Architecture was conceived as an ecological negotiation rather than a static object, and this adaptive logic reveals Tachusastra as an indigenous science of sustainable habitation.

The integration of these dimensions carpentry, geometry, proportion, ritual science, and environmental adaptation positions Tachusastra as a holistic framework of knowledge production unique to Kerala's architectural culture. Unlike fragmented modern systems that separate engineering, sustainability, design, and spirituality into distinct domains, Tachusastra synthesized them into a unified practice. This epistemological coherence is what allowed Kerala's timber traditions to produce buildings of exceptional durability, climatic responsiveness, and cultural continuity.

Therefore, examining Tachusastra as an indigenous epistemological framework fundamentally reframes it from vernacular craft to intellectual system. It emerges as a mode of architectural reasoning in which hereditary knowledge, empirical observation, sacred philosophy, and environmental intelligence coalesced into a civilizational technology. Such a perspective is critical not only for recovering marginalized architectural histories but also for expanding contemporary architectural theory to include plural systems of knowledge that challenge the universalizing assumptions of industrial modernity. In this light, Tachusastra offers not simply historical insight, but a viable epistemic model for rethinking architecture as an integrated science of life, place, and sustainability.

2.2.4 Ecology and sustainability: Timber architecture as environmental intelligence

Kerala's timber architecture evolved through continuous ecological negotiation with a humid tropical environment characterized by heavy monsoon rainfall, biological decay, seasonal variation, and forest abundance. Tachusastra demonstrates that traditional architecture was fundamentally ecological, grounded in resource intelligence, climatic responsiveness, and long-term sustainability. Material procurement itself reflected environmental consciousness: lunar timber harvesting practices indicate awareness that sap content, moisture behavior, and biological vulnerability varied according to seasonal and celestial cycles. Trees were often felled during specific lunar phases to reduce moisture retention and improve durability, suggesting empirical biological science embedded within craft traditions.

Species-specific timber selection further reveals advanced ecological intelligence, where wood was chosen according to density, grain orientation, fungal resistance, and structural suitability. Traditional seasoning practices reduced shrinkage and warping, while herbal preservative systems such as *ettukoottu* functioned as indigenous biochemical technology. This preservative science, rooted in natural compounds, protected timber from pests, fungal growth, and moisture degradation without synthetic intervention. Architectural systems reinforced these ecological strategies: elevated granite plinths acted as moisture barriers, internal courtyards moderated microclimates, and timber trelliswork functioned as sophisticated ventilation engineering by enabling continuous airflow and humidity regulation. Rather than decorative screens, trellis systems served as breathable environmental membranes that sustained thermal comfort and minimized decay. Together with steep roofs, deep overhangs, and *jwala* rain-deflection systems, these elements formed an architecture of preventive sustainability where environmental adaptation, maintenance, and material longevity were inseparable.

2.2.5 Joinery and structural intelligence: Craft as engineering science

One of Tachusastra's most remarkable dimensions is its advanced joinery logic, through which carpentry transcended craft to become structural engineering. Traditional timber structures in Kerala employed sophisticated joinery systems, including mortise-and-tenon assemblies, interlocking wooden joints, pegged frameworks, and specialized techniques such as *arukuduma* that minimized dependence on metal fasteners. In a moisture-rich environment where corrosion would compromise structural life, this approach demonstrates profound foresight. Joinery was not simply a method of connection; it was the foundation of structural resilience.

By relying on precisely calculated interlocking systems, Kerala's timber buildings distributed loads dynamically while allowing flexibility under environmental stress. Such systems were particularly significant in conditions of humidity-driven expansion, contraction, and movement. Joinery thus enabled architecture to "breathe" structurally, adapting to climatic pressures while maintaining integrity. This resilience was enhanced by rain-shedding systems such as *jwala* projections, overhangs, and carefully angled roof forms, which reduced direct water intrusion into vulnerable structural joints. The relationship between joinery and weatherproofing was therefore deeply integrated. Thai Kottaram demonstrates how structural systems, moisture defense, and repairability formed a unified engineering logic. Because damaged members could be selectively replaced without dismantling entire assemblies, Tachusastra embodied a regenerative lifecycle model. Joinery, in this context, becomes a form of indigenous systems engineering where precision, reversibility, and conservation converge.

2.2.6 Cosmology and sacred science: Architecture as ritualized knowledge

Beyond technical sophistication, Tachusastra operates within a cosmological worldview in which building is simultaneously physical, symbolic, ecological, and spiritual. Traditional Kerala carpentry was informed by sacred sciences articulated through Vastuvidya, Tantric ritual, and regional shastric traditions, where orientation, sequencing, and proportion were linked to cosmic order. Architecture was conceived not merely as shelter but as a mediator between body, environment, and universe.

This cosmological framework also shaped environmental practices. Lunar timber harvesting, for instance, was not solely ritualistic but reflected an integrated worldview in which celestial cycles, biological processes, and material science were interconnected. Similarly, rituals surrounding timber selection, consecration, and construction sequencing positioned architecture as a sacred ecological act. Measurements such as *angulam* and *manam* mediated between human scale and cosmic proportion, while *rekha* aligned built space with directional and spiritual order. Even preservative practices like *ettukoottu* can be understood within this framework, where natural materials, environmental ethics, and sacred responsibility intersected. The Tachan therefore functioned not merely as craftsman but as mathematician, environmental strategist, and ritual mediator. Through this integration of sacred science and technical intelligence, Tachusastra emerges as a holistic system in which granite plinths, trellis ventilation, rain-shedding geometries, joinery resilience, herbal preservation, and lunar harvesting are not isolated practices but interconnected dimensions of a civilizational knowledge system. Kerala's timber architecture thus reveals an indigenous paradigm where mathematics, ecology, engineering, and cosmology function as one unified architectural science.

3. CONTEMPORARY RELEVANCE

The contemporary relevance of Tachusastra lies in its capacity to challenge dominant paradigms of industrial modernity by offering an alternative architectural framework rooted in ecological intelligence, material restraint, and regenerative logic. At a historical moment marked by climate crisis, resource depletion, excessive embodied carbon, and the homogenization of global building practices, Kerala's traditional timber systems reveal that sustainable architecture need not emerge exclusively from new technologies, but may also be recovered from deeply localized systems of indigenous scientific knowledge. Tachusastra demonstrates how architecture can operate through preventive rather than corrective strategies anticipating moisture, decay, thermal stress, and material fatigue through design intelligence rather than technological dependence. Such principles resonate strongly with contemporary priorities in passive design, climate-responsive architecture, circular economies, and lifecycle sustainability.

The environmental systems embedded within Kerala's timber architecture granite plinths as moisture barriers, trelliswork as passive ventilation, jwala and overhang systems for rain management, species-specific timber science, herbal preservative technologies, and modular repairability align closely with current discourses on regenerative design and low-carbon construction. In particular, the cyclical maintenance philosophy of *jirnnoddhaarana* presents an indigenous model of preventive conservation that parallels contemporary resilience theory, where buildings are conceived not as disposable commodities but as evolving systems of stewardship. This positions Tachusastra as an important precedent for adaptive reuse, sustainable heritage conservation, and environmentally responsive design education.

Equally significant is Tachusastra's relevance to decolonial architectural discourse. Modern architectural theory has historically privileged industrialized materials, standardized metrics, and Eurocentric technological narratives while marginalizing hereditary craft systems as vernacular or pre-scientific. Repositioning Tachusastra as an indigenous technological epistemology challenges these hierarchies by asserting that systems of proportion, carpentry, ecology, and cosmology in Kerala constitute valid forms of architectural science. In this sense, the study contributes to broader efforts to recover suppressed knowledge traditions and expand architectural historiography beyond dominant canonical frameworks.

For contemporary practice, Tachusastra offers not a simplistic return to tradition, but a critical methodological resource. Its principles can inform modern timber innovation, sustainable detailing, climate-adaptive housing, material conservation, and interdisciplinary architectural pedagogy. By integrating embodied craft knowledge with current environmental challenges, Tachusastra provides a model through which architecture may reconcile technology with ecology, precision with culture, and innovation with continuity.

4. CONCLUSION

This research establishes Tachusastra as a sophisticated indigenous system of architectural science that transcends conventional understandings of carpentry as mere craft practice. Through its integration of mathematical systems (*angulam*, *mānam*, *rekha*), ecological adaptation, material science (*dravyavigyan*), structural engineering, preventive conservation, and sacred cosmology, Tachusastra emerges as a comprehensive epistemological framework that shaped Kerala's timber architecture with extraordinary precision and resilience. The analysis of Thai Kottaram, Travancore, confirms that this tradition functioned as an applied science of environmental intelligence, where every architectural decision from granite plinths and trellis ventilation to joinery systems and herbal preservation was embedded within a larger philosophy of sustainability and stewardship.

Far from representing a static vernacular past, Tachusastra reveals a dynamic and empirically refined body of knowledge that anticipated many principles now central to contemporary architectural discourse, including passive environmental control, circular material use, preventive conservation, and regenerative design. The integration of ritual science and cosmological order further demonstrates that traditional Kerala architecture cannot be adequately understood through technical analysis alone; rather, it operated through a holistic worldview in which material, environmental, structural, and spiritual dimensions were inseparable.

This study also underscores the urgent need to preserve hereditary artisan knowledge systems not solely as cultural heritage, but as intellectual and technological resources. As industrial modernity continues to generate ecological and epistemic crises, the recovery of indigenous systems such as Tachusastra offers critical pathways toward more sustainable and pluralistic architectural futures. By reframing Kerala's timber traditions within the intersecting discourses of sustainability, decoloniality, and architectural theory, this research contributes to a broader redefinition of what constitutes scientific knowledge in architecture.

Ultimately, the enduring significance of Tachusastra lies in its demonstration that architecture can be simultaneously ecological, mathematical, spiritual, and technologically rigorous. Kerala's timber architecture, therefore, should not be viewed merely as historical inheritance, but as an active repository of design intelligence capable of informing both conservation practice and future architectural innovation.

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Traditional Dwellings and Settlements

Working Paper Series

TRANSLATING MATERIAL TRADITION: SEM- BASED CHARACTERIZATION OF RED BRICKS IN MODERN SHANGHAI ARCHITECTURE

Shuming Zhang , Minghao Gao , Jingwan Fu

TRANSLATING MATERIAL TRADITION: SEM-BASED CHARACTERIZATION OF RED BRICKS IN MODERN SHANGHAI ARCHITECTURE



This study aims to investigate the micro-historical information embodied in modern Shanghai red bricks. The primary objective is to identify the representational differences among various types of red bricks and to establish a microscopic damage identification system for modern Shanghai red bricks based on the correlation between their pore microstructures and quantitative SEM image indices.

Red brick samples were collected from several representative modern buildings in Shanghai, including Renji & Co, the Library of Shanghai Jiao Tong University, and the Holy Trinity Church. Scanning Electron Microscopy (SEM) was employed as the main analytical tool to examine the microstructural characteristics and pore morphology of the samples. Grayscale morphological images were obtained at different magnifications and quantitatively processed to calculate key parameters such as pore size distribution, porosity index, aspect ratio, and roundness. Comparative analyses were conducted among different brick types. The findings reveal that: (1) there are significant representational differences between machine-made and handmade red bricks; (2) the oxidation surfaces of the red bricks exhibit distinct patterns of deterioration, including uneven firing during manufacturing, cyclic wet-dry conditions due to proximity to the Huangpu River, and salt migration-induced damage; and (3) lime-based surface finishing materials exert notable effects on the restoration of the “substrate–red brick wall” systems. This research provides a solid scientific foundation for the subsequent evaluation of durability, selection of restoration materials, and environmental adaptability design of modern historical buildings constructed with red bricks in Shanghai.

1. INTRODUCTION

Red brick in Shanghai’s modern architecture was not a silent building material.¹ It shaped the outward appearance of churches, schools, foreign firms, warehouses, and public buildings, while also recording, at a deeper level, the continuous negotiation among technological importation, local construction practices, urban environments, and later repair interventions in modern Shanghai. On the one hand, it was associated with industrial production, colonial trade, and the introduction of modern building technologies; on the other, it was continuously reshaped by local raw materials, construction experience, urban climate, and subsequent conservation practices. In this sense, modern red brick in Shanghai constitutes a material carrier of technological history, urban history, and conservation history. If it is understood only in terms of façade style or construction date, the manufacturing logic, environmental effects, and traces of repair embedded within the material itself are easily overlooked.² Shanghai’s modern architecture has not been preserved merely at the level of form; nor are building materials simply subordinate components of architecture. Rather, they form a critical basis for identifying and reconstructing heritage value.

This material identity is not merely a retrospective interpretation by contemporary researchers. As early as the beginning of the twentieth century, red-brick buildings in Shanghai had already been explicitly observed and

named in urban guidebooks and public writings.³ The Shanghai Handbook of 1918, for example, identified red brick as an important visual feature in its descriptions of urban landmarks such as the buildings along the Bund and Nanyang Public School. Holy Trinity Church was also long known as the “Red Chapel” or “Red Church” because of its red-brick interior and exterior walls.⁴ These historical publications, city guides, and official cultural records collectively indicate that red brick was not merely a structural material; it also participated in the formation of Shanghai’s modern visual order and public memory.

Existing studies on modern architecture and urban heritage in Shanghai have largely approached the subject through architectural style, urban governance, colonial modernity, historic-building registration, and conservation systems.⁵ Such research has effectively revealed how Shanghai’s modern buildings were selected, preserved, and reinterpreted within shifting political, economic, and social contexts. However, these studies tend to focus on the overall fate of buildings as urban heritage, while paying relatively limited attention to the microscopic level of the material itself.⁶

By contrast, research on the conservation of building materials emphasizes that the weathering of porous materials is rarely caused by a single factor. ICCROM has pointed out that moisture migration, salt crystallization, pore structure, surface treatment, and previous repairs jointly affect the deterioration of historic building materials.⁷ Studies on the conservation of historic brick structures have likewise emphasized that a brick wall should not be understood simply as an assemblage of individual bricks, but rather as a system composed of brick units, mortar joints, surface materials, and environmental conditions. These perspectives provide important methodological insights for the study of Shanghai red brick. If attention is limited to color, size, or visible surface weathering, it becomes difficult to assess the actual durability of the material or the compatibility of repair interventions. For Shanghai, a city located in a subtropical monsoon climate, the powdering, spalling, cracking, and surface-interface problems now observed in modern red brick should not be attributed simply to “natural aging.” Instead, they should be understood as the combined result of manufacturing methods, service environments, and repair interventions.⁸

Against this background, this study examines red-brick samples from modern buildings in Shanghai, including Renji & Co., the Shanghai Jiao Tong University Library, and Holy Trinity Church, as shown in Figure 1. Through scanning electron microscopy and image-based quantitative analysis, it investigates differences in pore morphology, surface deterioration, and interfacial characteristics among different brick materials. The current research design has shown that the samples not only display characteristic differences between handmade and machine-made bricks, but also reveal complex patterns of deterioration associated with uneven firing, wetting–drying cycles, salt migration, and lime-based surface materials.

The aim of this article is to reinterpret the formation mechanism of Shanghai’s modern architectural material

tradition through the identification of red-brick microstructures. Rather than simply asking how different red bricks differ from one another, the article further asks: how were these differences produced? How do they record the localization of architectural technology in modern Shanghai? And how do they affect present-day judgments concerning heritage conservation and repair?

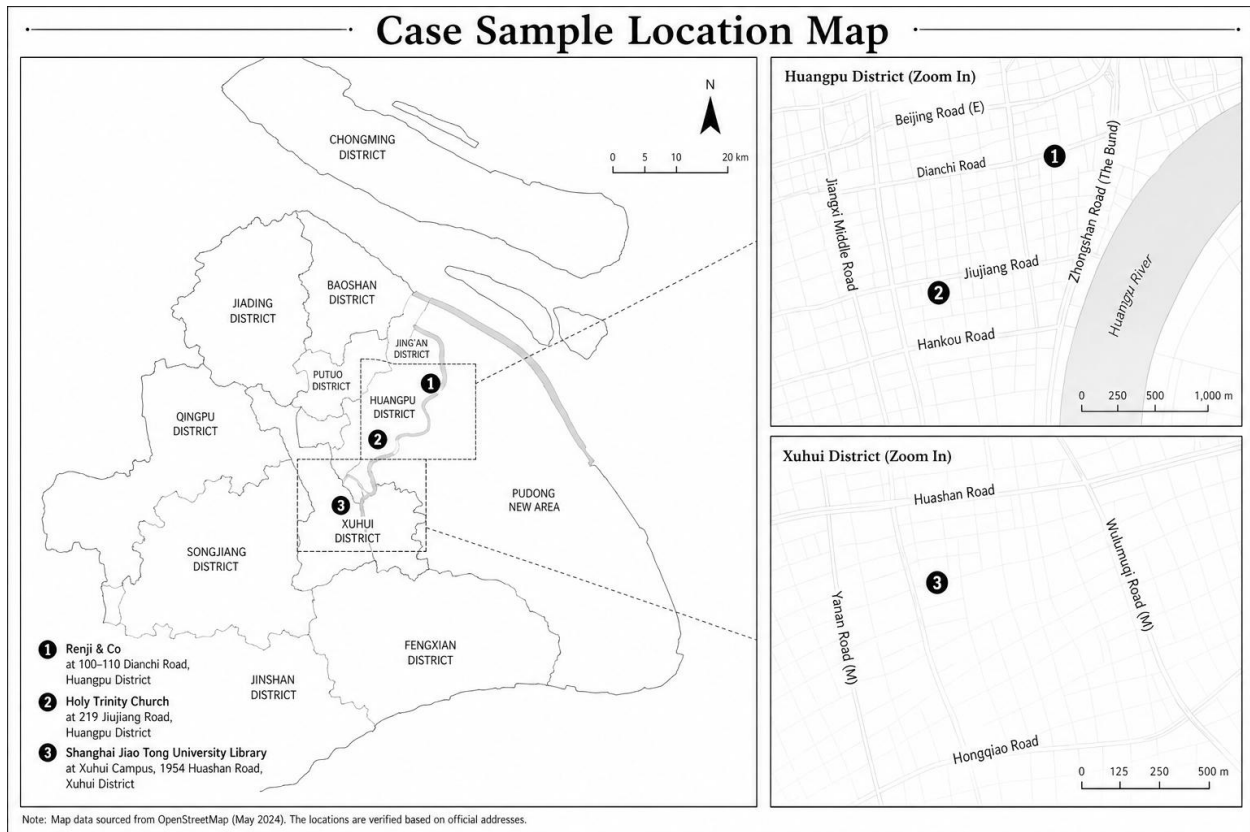


Figure 1: Case sample location map of the three red-brick buildings in modern Shanghai. (Source: Author).

To address these questions, the article proceeds on three levels. First, it compares the pore structures of different red-brick samples, identifying differences between handmade and machine-made bricks in terms of pore-size distribution, pore morphology, and surface fabric. Second, by relating these findings to surface deterioration, it analyzes the effects of uneven firing, humid waterfront environments, wetting–drying cycles, and salt migration on brick decay. Third, it incorporates lime-based surface materials into the analysis of the wall system, examining the compatibility among the red-brick substrate, mortar joints, surface treatments, and repair materials. In doing so, this article understands modern red brick in Shanghai as a “translated material tradition.” Its contribution lies in using SEM-based microstructural observation as an entry point to transform the internal structure of red brick into material evidence for understanding the localization of building technology, the mechanisms of deterioration, and conservation compatibility. This approach

provides a more precise analytical pathway for material identification, deterioration diagnosis, and repair decision-making in the conservation of modern red-brick buildings in Shanghai.

2. MODERN SHANGHAI AND THE TRANSLATION OF BRICK TRADITION

2.1. Shanghai as a Port-City Context

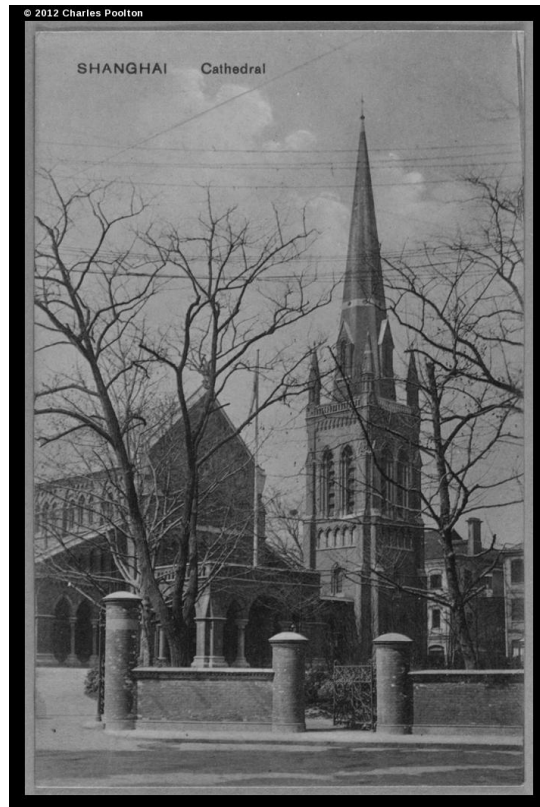


Figure 2: The Holy Trinity Cathedral, Shanghai, estimated 1893–1909. (Source: Virtual Shanghai, Image ID 386, Institut d’Asie Orientale Collection, accessed April 30, 2026.)

The emergence of red-brick architecture in modern Shanghai was closely related to the transformation of the city’s character after its opening as a treaty port. Following the signing of the Treaty of Nanjing in 1842, Shanghai became one of China’s ports open to foreign trade. Originally a county town and harbor grounded in Jiangnan regional commerce, it was rapidly incorporated into a new urban system shaped by Sino-foreign trade, shipping, finance, and concession governance.⁹ British merchants were the first to acquire trading and residential space in Shanghai, while American and French interests subsequently entered the city through the treaty system. Together, these forces produced a pattern of urban construction in which British, American, French, and other foreign powers participated, turning Shanghai into a point of convergence for Chinese and

Western culture and commercial activity.¹⁰

This treaty-port system redirected Shanghai's urban development. From the mid- to late nineteenth century onward, Shanghai was no longer merely a traditional administrative city or regional market center. It gradually developed into a modern metropolis driven by port trade, concession institutions, and new forms of public architecture.¹¹ Treaty-port urbanization required a large number of new building types, including foreign firms, warehouses, wharf-related facilities, banks, clubs, churches, schools, police stations, hospitals, and municipal infrastructure. These buildings differed from traditional dwellings, ancestral halls, guild halls, shops, and courtyard spaces in Jiangnan cities. They often demanded higher fire resistance, more regular façades, more stable wall structures, and architectural expressions better suited to the institutional image of modern public and commercial organizations. Because of its vivid color, regular masonry, capacity to form continuous façades, and relative durability, red brick gradually became an important material for the new architectural forms required during Shanghai's transformation into a treaty-port city.¹²



Figure 3: The Gibb Livingston & Co. Building (Renji & Co.), Shanghai, estimated 1908–1920. (Source: Virtual Shanghai, Image ID 1573, from Chen Congzhou and Zhang Ming, eds., *Shanghai jindai jianzhushi gao* 上海近代建筑史稿, 1988, 46; accessed April 21, 2026).

Yet red-brick architecture did not belong exclusively to the British sphere. American missionary, educational, and commercial networks also participated in the formation of modern public architectural space in Shanghai.¹⁴ In addition to commercial buildings such as Renji & Co. (Figure 3), Nanyang Public School (Figure 4) used red brick to create a regular, modern, and institutional campus image, and it subsequently

became part of the recorded urban landscape. French influence, meanwhile, shaped Shanghai's architectural space mainly through the French Concession, municipal roads, Catholic institutions, and residential district development. Although different national powers emphasized different architectural styles, they jointly promoted Shanghai's transformation from a traditional Jiangnan city into a modern hybrid metropolis, while also expanding the visibility of red-brick masonry architecture within the city.¹⁵

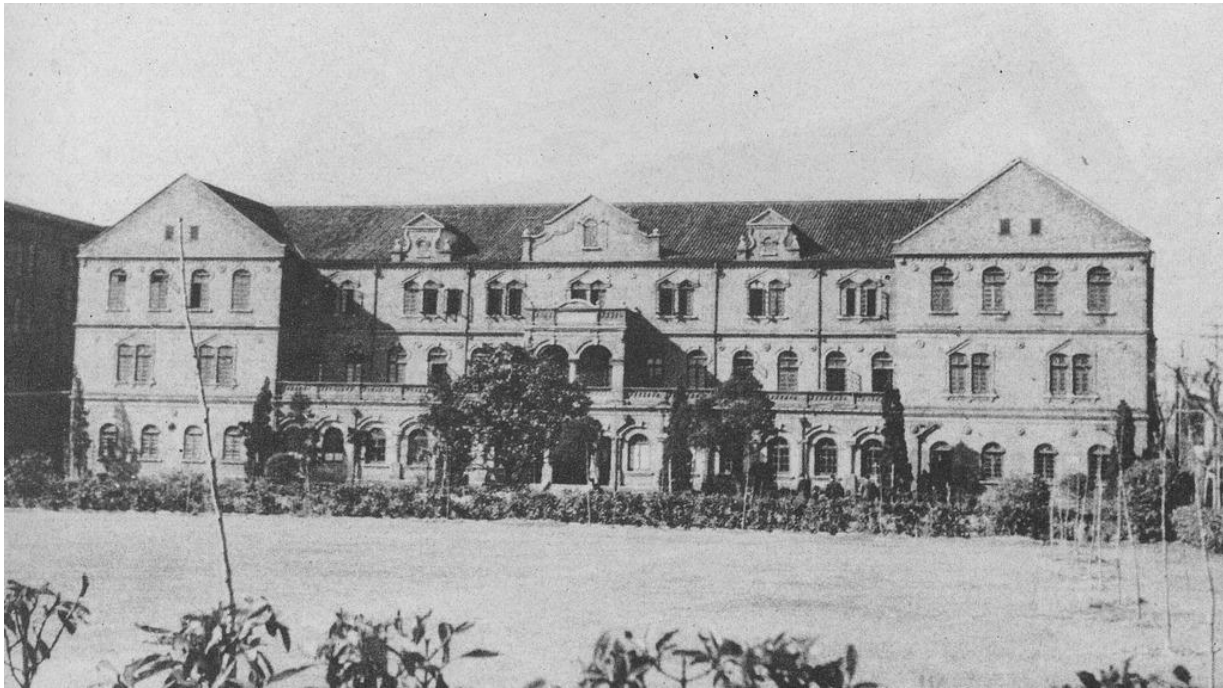


Fig. 4: Nanyang College, Shanghai. (Source: Virtual Shanghai, Image ID 1594, Institut d'Asie Orientale Collection; accessed April 30, 2026.)

The historical background of modern red-brick architecture in Shanghai may therefore be understood on three levels. First, it was related to Shanghai's incorporation into the Sino-foreign trade system: the treaty-port regime enabled British, American, French, and other commercial, religious, and educational institutions to enter the city. Second, it was connected to concession-based urban construction: the International Settlement and the French Concession generated substantial demand for new public buildings, commercial architecture, and infrastructure. Third, it was grounded in local building systems: although the forms and techniques of red-brick architecture were influenced by foreign architectural traditions, their construction, material supply, and practical realization still depended on local craftsmen and material markets in Shanghai and its surrounding regions. For this reason, red brick in Shanghai was not simply an "imported" material. Rather, it became a material imprint of the modern city, shaped jointly by foreign trade, concession development, and local urban construction.

2.2. Red Brick as Urban Image and Material Translation

Red brick in Shanghai was disseminated through the combined agency of British mercantile communities, missionary institutions, concession engineering systems, Western architects, and local building practices. Stimulated by foreign architectural demand, it soon entered the local production system.¹⁶ European-style red brick production in early Shanghai can be traced back to as early as 1858. In 1879, the Bailianjing Machine Brick and Tile Factory was established, further contributing to the gradual formation of a local production network.¹⁷ This indicates that early European red brick did indeed enter Shanghai through British shipping and trading systems, while also stimulating local imitation and manufacture. At the same time, studies of technological transformation in Shanghai's brick industry have recorded that the red bricks used in the reconstruction of Holy Trinity Church between 1866 and 1869 were produced by the British-owned Shanghai Brick Company, with the assistance of local Chinese workers. This suggests that the early circulation of red brick in Shanghai was no longer simply a matter of imported materials, but rather the result of interactions among foreign capital, British architectural traditions, local craftsmen, and regional production systems.¹⁸

In this process of dissemination, Holy Trinity Church represented a particularly important early node. During its reconstruction, the British architect George Gilbert Scott was commissioned for the design; construction began in 1866 and was completed in 1869. The building adopted a brick-and-timber structure, and its use of red brick itself became part of its architectural identity in Shanghai. The church was remembered not primarily because of its structural type, but because the image of the “Red Church” made red brick a visible and recognizable material feature within the city.¹⁹

From the perspective of its transmission, the development of red brick in Shanghai was shaped by both trade-driven introduction and the formation of a local production system. It ultimately spread visually across the city, entering urban imagery and public memory, and becoming an important component of Shanghai's modern architectural landscape.²⁰ This process is closely related to the objects examined in this study. Renji & Co., the Shanghai Jiao Tong University Library, and Holy Trinity Church correspond respectively to the use of red brick in commercial, educational, and religious architecture in modern Shanghai. They are not isolated cases, but different typological nodes within the broader chain of red-brick dissemination. For this reason, the analysis of these samples is not merely a material examination of several bricks; it is also a comparative investigation of how red brick entered different architectural types and developed distinct material conditions.²¹

In this sense, the “material translation” discussed in this article is not an abstract concept, but a historical result of the circulation of red brick in Shanghai. Red brick entered the city together with Western architectural ideas; through local brick production and construction systems, it became a visible urban skin of

modern Shanghai; and in the present context of heritage conservation, it has been transformed once again into a historical material that must be re-identified through microstructure, pore characteristics, and surface deterioration. The translation of red brick thus describes a continuous process: from a foreign architectural language, to a locally produced material, to an urban visual symbol, and finally to an object of conservation research. Accordingly, the SEM analysis in the following sections is not a purely materials-science investigation detached from historical context. Rather, it uses microscopic evidence to trace how red brick underwent material translation through the intertwined processes of foreign trade, architectural design, production, use, and repair in modern Shanghai.

2.3. Climate, Porosity, and Composite Wall Systems

After their construction, modern red-brick buildings in Shanghai did not cease to undergo material change. Shanghai's location near major waterways, together with its hot and rainy climate, produces an environment characterized by abundant moisture and frequent wetting–drying cycles. For porous materials such as red brick, this does not merely result in surface dampness; rather, moisture can enter, move through, and remain within the pore network of the brick, eventually leaving observable physical traces inside the material. Many of the common problems now found in Shanghai's modern red-brick buildings are closely related to this environmental mechanism. Red-brick walls often exhibit surface powdering, localized spalling, and related forms of deterioration. Although these problems may appear simply as “brick-surface damage” or “façade aging,” their causes are rarely singular. The firing quality of the brick, its original pore structure, water absorption capacity, moisture-release pathways within the wall, external rainwater penetration, fluctuations in air humidity, and the water-blocking or moisture-retaining effects of later repair materials may all contribute to the development of deterioration.²² The decay of materials such as brick, stone, and mortar is closely related to moisture movement, pore structure, salt activity, and existing repair layers. Therefore, the deterioration of historic brick cannot be judged only from surface appearance; it must be examined through the internal pore structure and moisture behavior of the material.

Historic red-brick walls are usually composite systems consisting of brick units, mortar joints, bedding mortar, plaster layers, surface coatings, cleaning traces, and later repair layers. Moisture and salts migrate among these materials rather than moving only within the brick body.²³ If a repair material is too dense, it may obstruct moisture evaporation from the wall and cause salts to concentrate within the old brick or at the interface between old and new materials. If the mortar joints or surface materials are too porous or weak, they may instead intensify rainwater penetration and surface erosion. Thus, the key issue in red-brick conservation is not only whether the color, dimensions, or bonding pattern of new materials resemble the original fabric, but whether old and new materials are compatible in terms of porosity, hygroscopic behavior,

vapor transmission, and interfacial stability.

Lime-based surface materials embody this systemic problem.²⁴ Lime mortar, lime plaster, and lime-based repair materials are often considered suitable for the conservation of historic masonry because of their vapor permeability and relative flexibility. In Shanghai's red-brick buildings, lime layers may function as materials that buffer moisture and protect the surface. However, when pore structures are incompatible, or moisture migration pathways are altered, they may also become new interfaces of deterioration. For this reason, the evaluation of lime-based materials must be further extended to the microscopic level, where their material fabric, pore characteristics, and interfacial behavior can be systematically analyzed.

3. SAMPLES AND METHODS

3.1 Case Selection and Sample Sources

This study selects Renji & Co, the Shanghai Jiao Tong University Library, and Holy Trinity Church as the main sampling cases (Figure 5). These buildings represent different typological contexts in the dissemination and use of red brick in modern Shanghai, and together they form the basic sample framework for examining material variation in Shanghai red brick. Sampling focused primarily on red-brick materials from the three buildings, with particular attention to representative brick surfaces, spalled areas, locally weathered zones, and areas where traces of surface treatment may be present. The surface condition of each sample was also recorded, including oxidation, powdering, cracking, salt efflorescence, and the attachment of lime-based surface materials.

To ensure comparability among the samples, they were organized according to building source, sampling location, surface condition, and observation purpose. Each sample group was linked to a specific building and sampling position, and its pore structure, particle-bonding condition, surface deterioration features, and interfacial relationships were further examined through SEM observation. In this way, the study connects the historical context of each building with the material object under analysis, preventing microscopic images from becoming isolated technical results detached from their architectural background.



Shanghai Jiao Tong University Library



Holy Trinity Church



Renji & Co

Figure 5: Current condition of the architectural samples. (Source: Photograph by the author).

3.2 SEM Observation and Image Acquisition

The observations were conducted using a ZEISS EVO 18 scanning electron microscope. The main working parameters were an EHT of 20 kV and a WD of 27 mm. Prior to observation, the samples were prepared as required by the testing procedure to ensure stable imaging of the selected areas. Image acquisition covered observation fields at different scales. Lower magnifications were used to identify overall pore distribution and surface fabric; medium magnifications were used to observe pore boundaries, particle bonding, and crack morphology; and higher magnifications were used to analyze localized deterioration, interfacial relationships, and possible salt- or lime-based attachments.

3.3 Quantitative Image Analysis

To avoid limiting SEM image analysis to subjective description, this study further employed ImageJ for quantitative processing of the microscopic images. The purpose of image quantification was to convert differences in pore morphology and surface structure among different brick samples into comparable data indicators. These indicators provide a basis for identifying typological differences between handmade and machine-made bricks, analyzing environmental deterioration mechanisms, and discussing repair compatibility in the following sections.

The analysis focuses on four main indicators. The first is pore-size distribution, which reflects the composition of pores at different scales within each sample. A more dispersed pore-size distribution generally indicates a more heterogeneous internal structure, which may be related to raw-material mixing, forming method, firing conditions, or later weathering. The second is the porosity index, which indicates the proportion of pore area within the image field. This indicator can be used to compare the relative looseness of different brick samples and to further discuss their risks of water absorption, moisture migration, and salt activity. The third is the aspect ratio, which describes the degree of elongation of pores. A higher aspect ratio

often suggests that pores tend to develop into crack-like forms, which may be associated with firing shrinkage, external stress, wetting–drying cycles, or the expansion of weathering. The fourth is roundness, which reflects the regularity of pore boundaries. More regular pores may be associated with relatively stable forming and sintering processes, whereas fragmented and irregular pore boundaries may reflect uneven raw materials, insufficient firing, or later deterioration.

Through these indicators, this study is able to compare, at a quantitative level, differences among samples from different buildings and with different surface conditions.

4. MANUFACTURING DIFFERENCE AND MATERIAL TYPOLOGY

4.1 Handmade and Machine-Made Bricks

SEM images of the three sample groups indicate that modern red brick in Shanghai was not a homogeneous industrial material. Rather, it reveals a continuous spectrum ranging from handmade brick and early non-standardized production to mechanized manufacture. The samples from Renji & Co., the Shanghai Jiao Tong University Library, and Holy Trinity Church differ in particle fabric, pore morphology, sintering condition, and surface deposition. These differences suggest that brick typology was shaped not only by manufacturing methods, but also by building type, service environment, and later repair processes.

The Renji & Co. sample appears closer to handmade brick or early non-standardized brick. In its SEM images (Figure 6), irregular fragments, loose fine particles, lamellar exfoliation, open pores, and rough pore walls can be observed. The particle-size grading is highly uneven, and the continuity of the matrix is relatively weak. Although sintered fragments are locally preserved, the overall compactness of the material is limited, indicating insufficient raw-material screening, low compaction during molding, and uneven firing. Such morphology may be understood as the result of the combined effects of manual production and local material conditions in the early stage of red-brick manufacture.²⁵

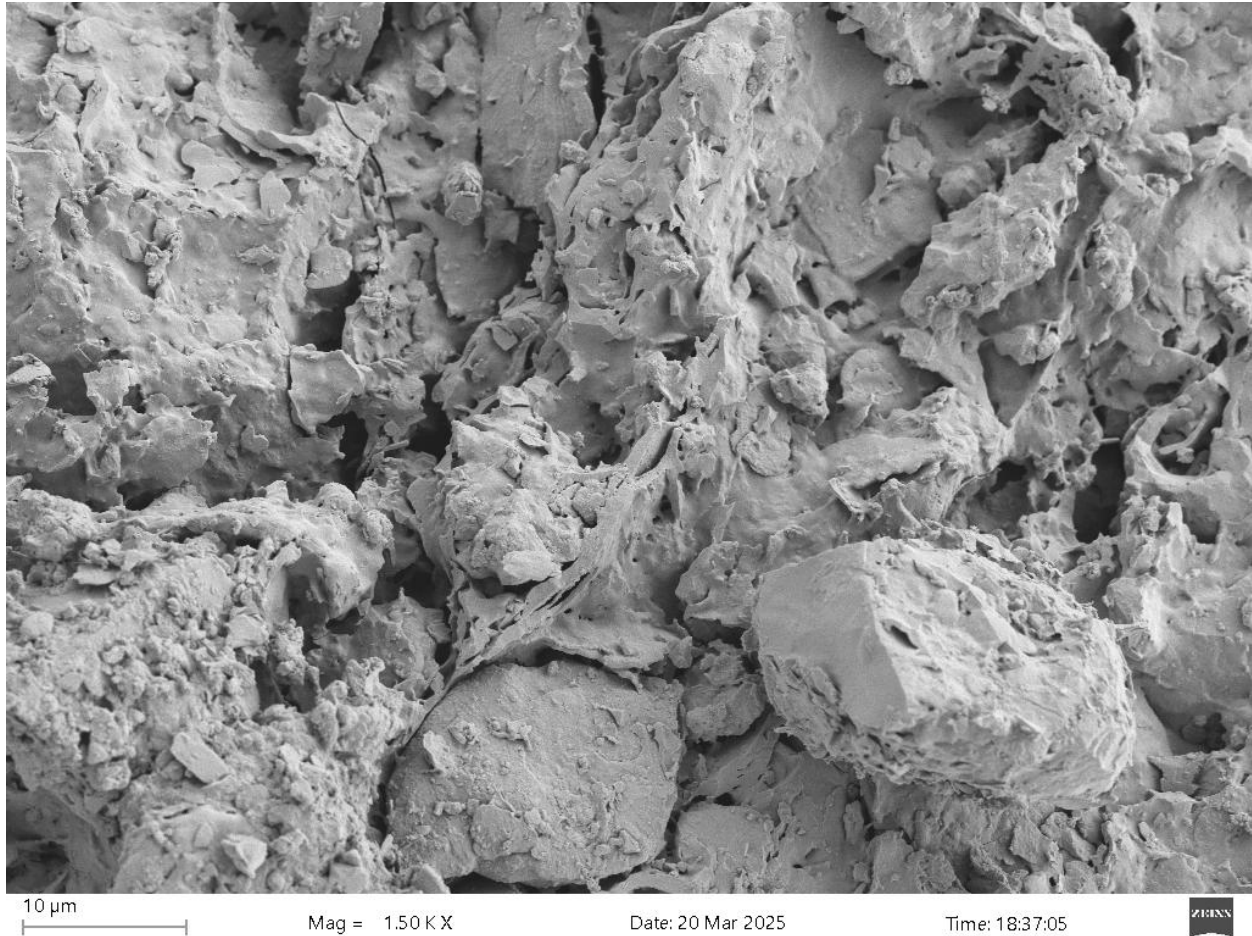


Figure 6: SEM images of the brick sample from Renji & Co. (Source: Photographs by the author).

The Shanghai Jiao Tong University Library sample, by contrast, tends more toward machine-made or semi-machine-made brick (Figure 7). Its matrix fragments are relatively regular, and the local sintering condition appears more stable. It does not show the pronounced lamellar exfoliation or highly heterogeneous structure observed in the Renji & Co. sample. However, a large number of acicular, rod-like, or flaky crystals are distributed across the surface and within the pores, indicating that the present morphology has been affected by later moisture migration, salt activity, or recrystallization of lime-based materials.²⁶ This sample therefore reflects the superimposition of a relatively regular mechanized matrix and traces of environmental deterioration.

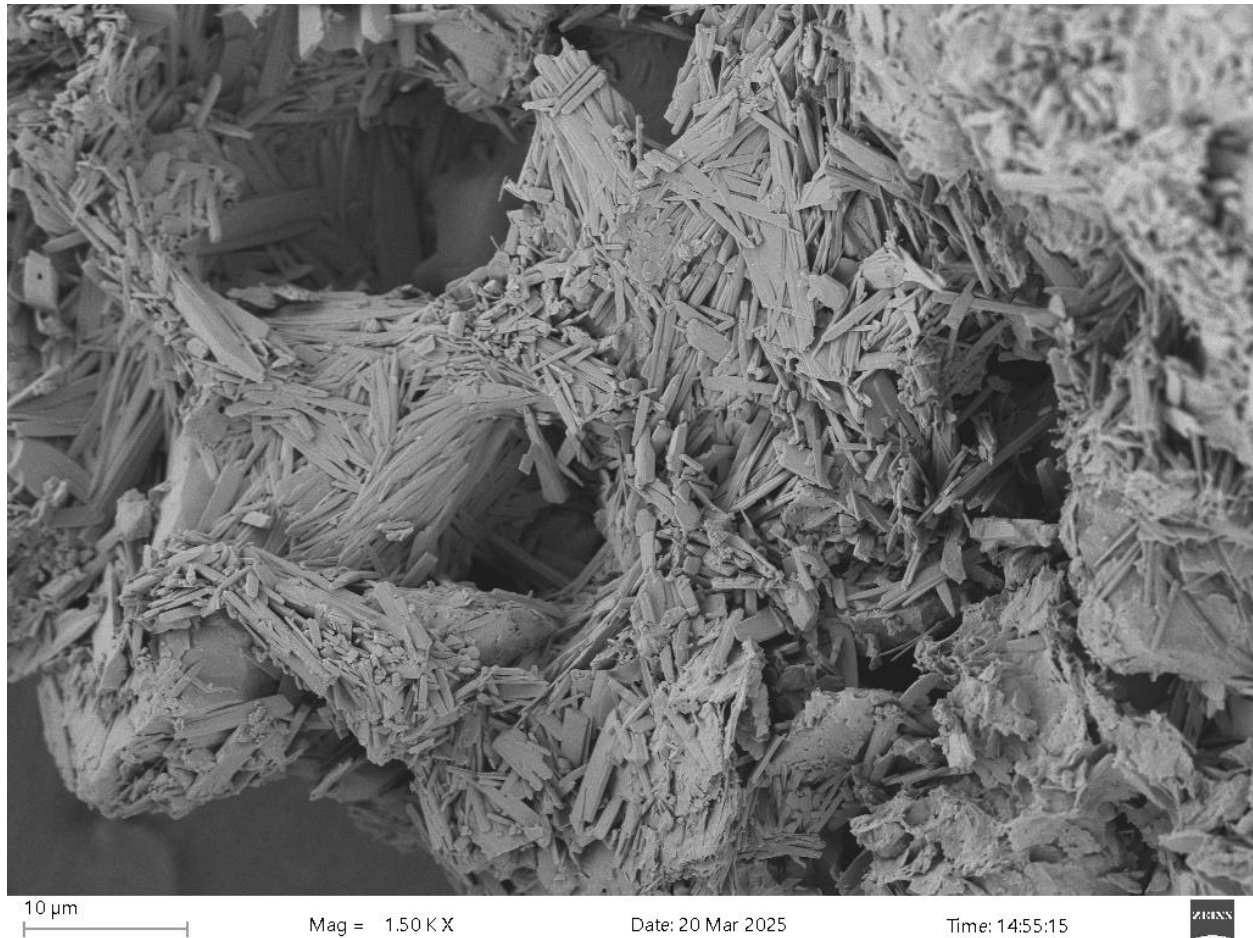


Figure 7: SEM images of the brick sample from Renji & Co. (Source: Photographs by the author).

The Holy Trinity Church sample shows a more evident transitional character (Figure 8). Its SEM images reveal both locally dense sintered matrices and blocky fragments, fine-particle agglomerations, microcracks, and surface powdering.²⁷ As one of the earlier red-brick religious buildings in Shanghai, Holy Trinity Church should not be simply classified within a mature machine-made brick system. Instead, its brick material more likely reflects an intermediate stage in which red-brick production was being transformed from an imported architectural technology into a localized production system during the mid- to late nineteenth century.

These observations show that the distinction between handmade and machine-made bricks is not merely a matter of technical terminology; it is embedded in the internal organization of the material itself. Handmade bricks or early non-standardized bricks generally exhibit complex raw-material grading, uneven particle bonding, developed open pores, and weak interfaces. Machine-made or semi-machine-made bricks, by contrast, usually show more stable particle organization and a more continuous sintered matrix.²⁸ However, under Shanghai's humid and warm environmental conditions, and through long-term repair interventions,

original manufacturing differences may be rewritten by environmental deposition, salt migration, and surface materials.

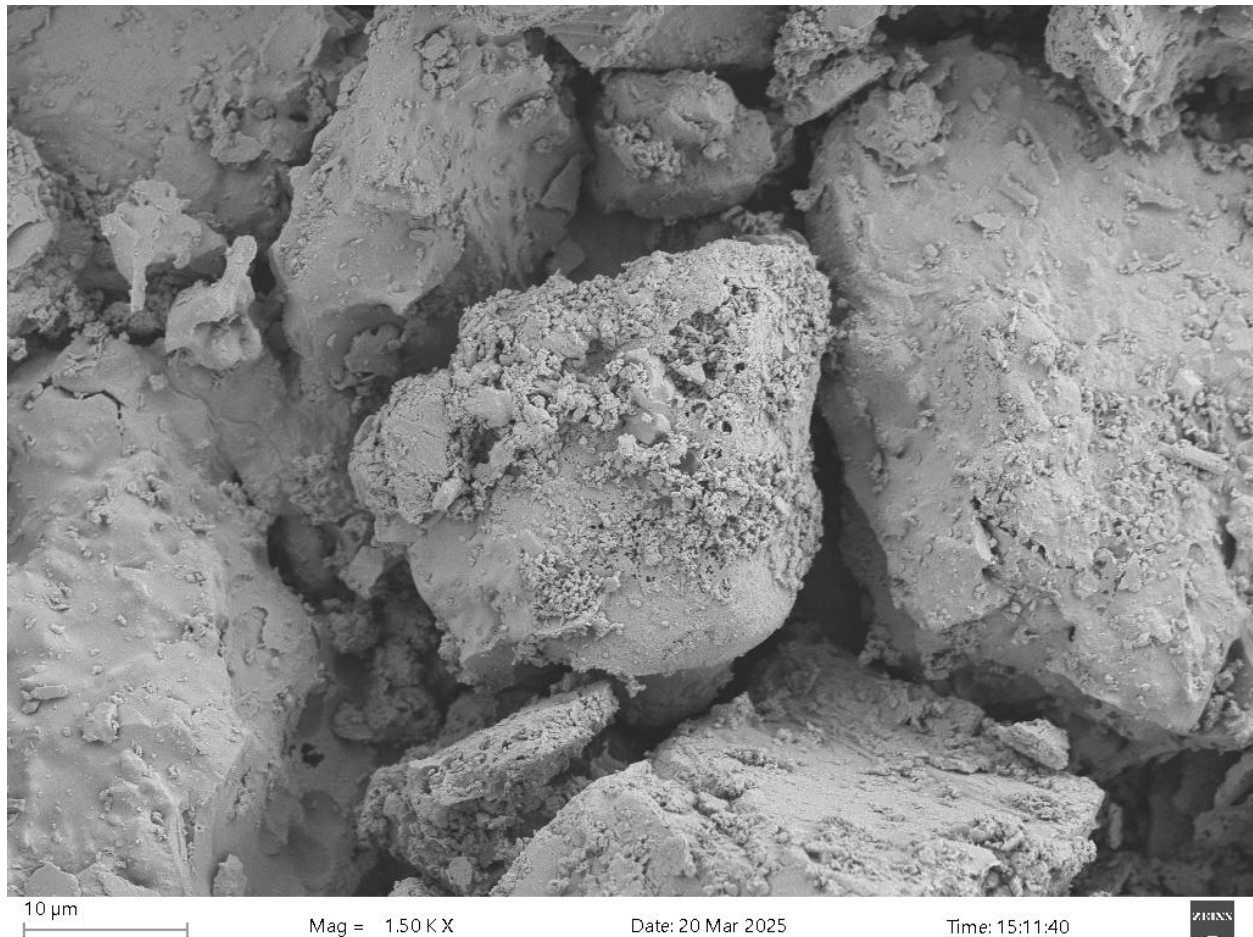


Figure 8: SEM images of the brick sample from Renji & Co. (Source: Photographs by the author).

Taken together, the three sample groups suggest that modern red brick in Shanghai should be understood as a dynamic material spectrum. Renji & Co. represents stronger handmade or early non-standardized characteristics; the Shanghai Jiao Tong University Library reflects the more regular matrix of mechanized or semi-mechanized brick; and Holy Trinity Church occupies a position between the two. Such typological differences indicate that the material history of modern red-brick architecture in Shanghai was not a linear process of industrialization. Rather, it was shaped by the interaction of imported technology, local production, architectural function, and urban environment.

4.2 Pore Morphology and Typological Indicators

To further verify the typological differences among the three groups of red-brick samples, quantitative image analysis was conducted on the representative SEM images. First, in terms of pore-size distribution, all three sample groups are dominated by micropores in the range of 0.5–1 μm , but the proportions of larger pores differ. In the Renji & Co. sample, pores of 1–2 μm account for 16.89%, while pores of 2–5 μm account for 3.82%. In the Shanghai Jiao Tong University Library sample, pores of 1–2 μm account for 14.65%, and those of 2–5 μm account for 4.83%. In the Holy Trinity Church sample, pores of 1–2 μm account for only 9.93%, while pores of 2–5 μm account for 2.69%. These results indicate that the Renji & Co. and Shanghai Jiao Tong University Library samples contain a higher proportion of medium- and large-scale pores, whereas the pore-size distribution of the Holy Trinity Church sample is more concentrated in the smaller-pore range. For handmade bricks or early non-standardized bricks, a higher proportion of large pores and a more dispersed pore-size distribution generally reflect uneven raw-material mixing, insufficient compaction during molding, and inadequate control of firing conditions. By contrast, a more concentrated pore-size distribution may suggest more complete local sintering or a relatively stable forming process.

Second, in terms of the porosity index (Table 1), the Shanghai Jiao Tong University Library sample records the highest value, at 6.612%, followed closely by the Renji & Co. sample, at 6.204%. The Holy Trinity Church sample shows the lowest value, at 4.142%. A higher porosity index does not necessarily mean that the material has already suffered severe deterioration, but it does indicate that the brick body contains more space for moisture ingress, retention, and migration.²⁹ The relatively high porosity of the Renji & Co. sample is consistent with its lamellar exfoliation, open pores, and weak interfacial morphology, supporting its identification as handmade brick or early non-standardized brick. Although the Shanghai Jiao Tong University Library sample is closer to machine-made or semi-machine-made brick, its relatively high porosity suggests that it has been significantly affected during long-term service by moisture migration, salt activity, or secondary crystal deposition. The lower porosity of the Holy Trinity Church sample indicates a relatively dense local matrix; however, this does not mean that its state of preservation is necessarily better, since its surface powdering and microcracks may still have resulted from the combined effects of early production heterogeneity and long-term environmental exposure.

Third, in terms of aspect ratio, the Shanghai Jiao Tong University Library sample has the highest value, at 2.593, followed by Renji & Co. at 2.482 and Holy Trinity Church at 2.213. A higher aspect ratio indicates that pores tend to be more elongated or crack-like in form. Such pores are often not simple closed air voids; rather, they may be associated with firing shrinkage, weak interparticle interfaces, external stress, or the expansion of later weathering.³⁰ The relatively high aspect ratio of the Renji & Co. sample corresponds to its

lamellar exfoliation and layered weak planes, indicating that many of its pores have developed along particle boundaries in crack-like forms. The Shanghai Jiao Tong University Library sample has the highest aspect ratio, suggesting that its pore morphology is the least stable. This may be related to secondary crystal growth, moisture migration, and the expansion of pore boundaries. By comparison, the lower aspect ratio of the Holy Trinity Church sample suggests that its pores are relatively shorter and less elongated, although a certain tendency toward crack-like development remains.

Samples	Porosity Index (%)	Mean Pore Diameter (μm)	Median Pore Diameter (μm)	D10 μm	D90 μm	Mean Aspect Ratio	Mean Roundness
Renji & Co	6.307	0.785	0.604	0.398	1.377	2.421	0.406
Renji & Co	6.102	0.770	0.581	0.389	1.333	2.544	0.371
Shanghai Jiao Tong University Library	7.254	0.862	0.615	0.402	1.674	2.690	0.370
Shanghai Jiao Tong University Library	5.970	0.741	0.563	0.398	1.288	2.497	0.384
Holy Trinity Church	2.876	0.639	0.525	0.389	0.991	2.292	0.403
Holy Trinity Church	5.408	0.735	0.569	0.389	1.146	2.133	0.413

Table 1: Quantitative data of the brick samples (Source: Created by the author).

Finally, in terms of roundness, all three sample groups show relatively low values, indicating that pore boundaries are generally irregular. Among them, the Holy Trinity Church sample has the highest roundness value, at 0.408, followed by Renji & Co. at 0.388, while the Shanghai Jiao Tong University Library sample has the lowest value, at 0.377. Higher roundness usually indicates relatively intact pore boundaries, which may be associated with more complete sintering or more stable forming conditions. Lower roundness, by contrast, suggests fragmented, elongated, or collapsed pore boundaries, which may be related to raw-material agglomeration, pore deformation, particle debonding, or later damage. The lowest roundness value in the Shanghai Jiao Tong University Library sample indicates that its pore boundaries are the most irregular, corresponding to the abundant acicular and flaky secondary crystals and surface deposits observed in the SEM images. The relatively low roundness of the Renji & Co. sample is more likely associated with original material heterogeneity and the development of weak interfaces. The comparatively higher roundness of the Holy Trinity Church sample suggests that its local pore morphology is more convergent, although it still does not reach the state of regular sintered pores.

Taken together, the four indicators show that the Renji & Co. sample is characterized by relatively high porosity, a high aspect ratio, and low roundness. Combined with the lamellar exfoliation, rough pore walls, and complex particle grading observed in its SEM images, these features support its identification as handmade brick or early non-standardized brick. The Shanghai Jiao Tong University Library sample, although possessing the relatively regular matrix of machine-made or semi-machine-made brick, shows high porosity, large average pore size, and high aspect ratio, as well as the lowest roundness. This indicates that later moisture migration, salt activity, or crystal deposition has significantly rewritten its pore morphology. The Holy Trinity Church sample has the lowest porosity and average pore size, suggesting a relatively dense local matrix; however, its microcracks and surface powdering still indicate a transitional condition shaped by both early red-brick production and long-term environmental action.

4.3 From Typology to Material History

The pore indicators and SEM morphological differences discussed above show that brick typology is not merely the result of experimental classification. Rather, it represents the material traces left within the brick body by different production regimes. The strong heterogeneity, relatively high porosity, and pronounced lamellar exfoliation observed in the Renji & Co. sample suggest a possible association with handmade molding, insufficient raw-material screening, and early non-standardized firing. In the Shanghai Jiao Tong University Library sample, the coexistence of a relatively regular sintered matrix and later crystal deposition reflects the superimposition of mechanized or semi-mechanized production and long-term environmental action. The transitional characteristics of the Holy Trinity Church sample, meanwhile, more closely correspond to the composite condition of early Shanghai red brick as it developed among imported building technologies, local production conditions, and long-term service environments. In this sense, the microstructure of red brick records not only material performance, but also production methods, technological control, and histories of use.

The coexistence of machine-made and handmade bricks within the same city, and in the same or closely related architectural contexts, indicates that the development of building materials in modern Shanghai was not a linear process of industrialization. Although modern Shanghai was influenced by Western architectural systems, concession-based engineering practices, and industrial brickmaking technologies, local material markets, craftsmen's experience, construction organization, and cost conditions continued to shape building production. In other words, machine-made brick did not immediately replace handmade brick, nor did industrial production completely eliminate local variation. On the contrary, modern red-brick architecture in Shanghai presents a multi-sourced material condition: imported technologies provided new architectural forms and production objectives, while local production systems determined how these materials were

actually manufactured, transported, and laid in construction.

This typological variation helps us reconsider the supply of materials and modes of construction in modern Shanghai architecture. Different building types did not require red brick in the same way. Churches, schools, foreign firms, and public buildings may have sought more regular façade effects and more stable structural performance, but actual material selection was still conditioned by production capacity, transportation networks, construction schedules, and later repair practices. The samples from Renji & Co., the Shanghai Jiao Tong University Library, and Holy Trinity Church respectively represent the use of red brick in commercial, educational, and religious architecture. Their differences indicate that there was no single “standard material” for red brick in Shanghai. Instead, when red brick entered different building systems, it acquired distinct microstructural conditions according to building function, funding sources, construction teams, material supply, and maintenance history.

Therefore, the significance of red-brick typology lies not only in distinguishing “handmade brick” from “machine-made brick.” More importantly, it reveals the complexity of the building-material system in modern Shanghai. Materials all referred to as red brick may have originated from different production regimes, undergone different construction processes, and developed different deterioration pathways in different environments. The more numerous weak interfaces and open pores in handmade bricks point to the limitations of local material experience and early brickmaking control. The more stable matrix structure of machine-made bricks reflects the industrial pursuit of regularity and homogeneity. Yet the transformation of both types under long-term humid and warm conditions, as well as through repeated repair interventions, shows that material history does not end at the moment of production; it continues to be rewritten through use and maintenance.

Viewed from this perspective, different red-brick types are themselves the result of “material-tradition translation.” Shanghai red brick was neither a simple copy of imported industrial materials nor a natural continuation of traditional local brickwork. Rather, it was a historical product formed among industrial brickmaking technologies, local craftsmen’s knowledge, urban construction demands, and long-term environmental action. These bricks compressed industrialization, local craft, architectural function, and urban environment into a single architectural skin. For this reason, the analysis of red-brick microstructure is not a materials test detached from architectural history. Instead, it offers a way to re-enter the history of modern Shanghai architecture through material typology. Within pores, particles, and interfaces, the production systems, construction realities, and conservation problems of modern Shanghai become visible once again.

5. CONSERVATION AND COMPATIBLE REPAIR

5.1 Damage Mechanisms: From Surface Symptoms to Microstructure

Deterioration in modern red-brick buildings in Shanghai is often first observed as visible façade-level symptoms: surface powdering, localized spalling, uneven coloration, loosened mortar joints, white salt efflorescence, surface accretions, and debonding of repair layers. These phenomena are reflected to varying degrees in the samples from Renji & Co., the Shanghai Jiao Tong University Library, and Holy Trinity Church. Although they may appear to be the natural aging of architectural surfaces, they are in fact closely related to manufacturing differences, Shanghai's humid waterfront environment, long-term service conditions, and later repair interventions. Therefore, the diagnosis of red-brick deterioration should not remain at the level of "surface damage," but should extend into the pore structure, particle bonding, and surface interfaces of the brick body.

The three sample groups show that the deterioration mechanisms of modern red brick in Shanghai are not identical. In the Renji & Co. sample, irregular fragments, loose fine particles, lamellar exfoliation, open pores, and rough pore walls are visible, indicating the presence of numerous weak bonding interfaces and a heterogeneous matrix. These characteristics make it easier for moisture to enter the brick body along particle boundaries and lamellar weak planes. Under repeated wetting–drying cycles, the bonding between particles is gradually weakened, eventually resulting in surface powdering and lamellar spalling. Its deterioration is therefore not caused simply by external erosion, but by the amplification of original material heterogeneity through long-term environmental action.

The Shanghai Jiao Tong University Library sample presents a different mechanism. Its brick matrix is relatively regular, but the SEM images show numerous acicular, rod-like, and flaky crystals attached to particle surfaces and distributed within pores. This indicates that later moisture migration, soluble-component deposition, or recrystallization of lime-based materials may have played a significant role in the formation of deterioration. In this case, decay is not primarily characterized by an originally loose matrix. Rather, a relatively stable machine-made or semi-machine-made brick body has been rewritten during long-term service by moisture, salts, and surface materials. In other words, a more regular brick body does not necessarily imply a lower risk of deterioration. Once the pore network allows moisture migration, salt crystallization and secondary deposition may still lead to pore expansion, interfacial pressure, and surface instability.

The Holy Trinity Church sample reveals a more complex pattern of composite deterioration typical of early red-brick architecture. Its SEM images show both locally dense sintered matrices and fine-particle agglomeration, rough pore walls, microcracks, and localized powdering. This suggests that the red brick of

Holy Trinity Church retains the firing and material heterogeneity of early red-brick production, while also having undergone continuous weathering in a long-term urban environment. As one of Shanghai's early red-brick churches, its deterioration should not be understood merely as weathering in a general sense. Instead, it should be interpreted within a framework that brings together early red-brick material characteristics, the prolonged use of religious architecture, and subsequent histories of maintenance.

The three sample groups indicate that surface deterioration in Shanghai's red-brick buildings often develops along a pathway from microstructure to macroscopic damage. First, original differences in firing and raw-material grading determine the initial distribution of pores and weak interfaces within the brick body. Second, moisture in Shanghai's humid and warm environment enters the wall through open pores and mortar joints, repeatedly acting through adsorption, evaporation, and wetting–drying cycles. Third, soluble salts or mobile components from lime-based surface materials may crystallize, deposit, or react again within pores or at interfaces. Ultimately, these processes jointly lead to weakened particle bonding, microcrack expansion, surface powdering, lamellar spalling, and debonding of repair layers.

Therefore, the same surface phenomena, such as spalling or powdering, may correspond to different material mechanisms. The Renji & Co. sample highlights particle disintegration controlled by an originally heterogeneous matrix and weak interfaces. The Shanghai Jiao Tong University Library sample emphasizes the rewriting of the pore system by moisture migration and secondary crystal deposition. The Holy Trinity Church sample presents a composite condition in which early sintering characteristics overlap with long-term environmental weathering. For this reason, the conservation of modern red-brick buildings in Shanghai should not determine repair methods solely according to surface categories of deterioration. Instead, it should identify different sources of deterioration through microstructural analysis.

5.2 Compatibility Beyond Color and Size

The repair of modern red-brick buildings in Shanghai often begins with an immediate visual concern: whether replacement bricks match the original wall in color, whether their dimensions are similar, and whether the bonding pattern appears harmonious. These criteria are certainly important for maintaining the continuity of historic façades, especially because red brick has a strong visual identity in Shanghai's modern architecture. However, the sample analysis above has shown that differences among red bricks are not confined to their external appearance.

For red-brick walls, the core of compatibility lies first in the pore relationship between old and new materials. As a porous material, red brick allows moisture and soluble salts to migrate through pores, mortar joints, and repair interfaces. If replacement bricks or repair materials are too dense, moisture within the wall may be

unable to evaporate, causing salts to crystallize inside the old brick or at the interface between old and new materials. This may lead to powdering, spalling, and edge damage. If the repair material is too porous, it may absorb excessive rainwater and turn the repaired area into a new entry point for deterioration. Therefore, the selection of repair materials should not pursue surface resemblance alone, but should also consider porosity, pore-size distribution, connectivity, and water-absorption behavior.

Compatibility also involves the coordination of mechanical and hygrothermal behavior. Shanghai's red-brick buildings have long existed in a humid urban environment, where walls continuously undergo moisture absorption, drying, thermal expansion and contraction, and localized salt crystallization. If repair mortar or replacement brick is too strong, shrinks excessively, or has an overly high elastic modulus, the old brick may become the weaker part of the wall, concentrating stress near brick edges or mortar joints. Many repairs that appear structurally sound may restore façade integrity in the short term, but in the long term they may cause interfacial cracking, debonding, or preferential damage to the original brick. Thus, suitable repair materials for modern red-brick buildings in Shanghai are not necessarily the strongest or densest materials. Rather, they should be able to release moisture together with the original brick, deform compatibly, and distribute environmental stress in a moderate manner.

This article therefore argues that compatible repair for modern red-brick buildings in Shanghai should include at least four dimensions. The first is morphological compatibility: color, dimensions, bonding pattern, and surface texture should preserve the visual continuity of the historic façade as far as possible. The second is pore compatibility: the porosity, pore-size distribution, and water-absorption capacity of new and old bricks and mortars should be relatively coordinated, so as to avoid creating barriers to moisture release or zones of excessive water absorption. The third is interfacial compatibility: brick units, mortar joints, lime layers, and repair materials should maintain stable adhesion and a moderate capacity for deformation, avoiding hidden cracks and debonding. The fourth is environmental compatibility: repair strategies should respond to Shanghai's humid and warm climate, rainfall, salt activity, and the existing moisture condition of historic walls, rather than treating red-brick façades as static, dry, and homogeneous surfaces. The repair of modern red-brick buildings in Shanghai should not take surface uniformity as its ultimate goal. Instead, it should be based on maintaining the stability, breathability, and historical authenticity of the wall system.

5.3 Lime-Based Surface Materials

Based on the sample observations in this study, the repair of plaster and surface layers in historic buildings is especially important in Shanghai's red-brick architecture. The presence of numerous acicular and flaky crystals in the Shanghai Jiao Tong University Library sample suggests that moisture migration, soluble-component deposition, or recrystallization of surface materials may have contributed to deterioration. The loose fine

particles, lamellar exfoliation, and open pores in the Renji & Co. sample should be understood in relation to the constructional relationship between exposed brick walls and lime pointing. The powdering and microcracks in the Holy Trinity Church sample need to be interpreted in connection with its early red-brick matrix, humid and warm environment, and multiple phases of repair and maintenance. These observations show that red-brick deterioration is often not an isolated process occurring within the brick body alone, but is gradually formed among brick units, mortar joints, surface materials, and the surrounding environment.

Therefore, when repairing modern red-brick buildings in Shanghai, it is first necessary to determine whether the wall originally had lime pointing, lime plaster, limewash, or other surface treatments. If the historic surface layer itself forms part of the building's material authenticity, its indiscriminate removal may damage the original moisture-regulating mechanism and erase historical information. If modern cement or high-strength repair materials are used to replace lime-based materials, the excessive strength, overly dense pore structure, and obstruction of moisture release may instead accelerate the deterioration of old bricks. A more appropriate strategy is to identify the history of the original surface layer, its pore structure, and its interfacial condition, and then select repair materials with moderate strength, compatible vapor permeability, maintainability, and compatibility with the original brick.

The discussion of lime-based surface materials thus returns to the central argument of this article: the conservation of red-brick buildings in Shanghai is not about restoring a neat and uniform appearance, but about maintaining a historically formed material relationship. Brick units, mortar joints, lime layers, repair traces, and the urban environment together constitute the heritage value of red-brick architecture. Only when these layers are understood as an integrated whole can repair avoid shifting from “conservation” toward “renewal,” allowing red-brick walls to continue to exist in a readable, maintainable, and interpretable form.

6. CONCLUSION

This article examined red-brick samples from three modern buildings in Shanghai — Renji & Co., the Shanghai Jiao Tong University Library, and Holy Trinity Church — through SEM microscopic observation and ImageJ-based quantitative analysis. It revealed differences in particle fabric, pore morphology, sintering condition, and surface deposition among the samples. The study shows that Shanghai red brick was not a homogeneous industrial material. Rather, it formed a continuous spectrum ranging from handmade brick and early non-standardized brick to machine-made or semi-machine-made brick. The Renji & Co. sample exhibits strong heterogeneity and weak interfacial characteristics; the Shanghai Jiao Tong University Library sample shows the coexistence of a relatively regular matrix and later crystal deposition; and the Holy Trinity Church sample presents a transitional condition shaped by the overlap of early red-brick production and long-term

environmental weathering. These findings indicate that modern red brick in Shanghai was not a simple transplantation of foreign industrial materials. Instead, within the context of the treaty-port city, it emerged as a “translated material tradition” jointly shaped by imported building technologies, local material production, craftsmen’s experience, urban environments, and later repair interventions.

ACKNOWLEDGEMENTS

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Traditional Dwellings and Settlements

Working Paper Series

INHERITANCE OF MATERIAL IN A FAST- GROWING CITY: A SEMIOTIC READING OF MOSAIC TILES IN HONG KONG

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INHERITANCE OF MATERIAL IN A FAST-GROWING CITY: A SEMIOTIC READING OF MOSAIC TILES IN HONG KONG



This research examines how vernacular architectural materials, specifically mosaic tiles in Hong Kong, mediate cultural meaning and place identity through a semiotic lens. It moves beyond functional readings of materials to analyze how visual narratives are organized on everyday surfaces. By treating mosaic tiles as active semiotic agents rather than neutral finishes, the study offers new insights into local architectural practice and urban living.

1. INTRODUCTION

1.1. Research Background

Mosaic tiles, composed of small tesserae in materials such as ceramic, glass, stone, and metal, have been widely employed as cladding systems in Hong Kong's built environment since the post-war period, particularly on exterior concrete façades. Typically produced as small-format units (often around 19 × 19mm) in matte or glossy finishes, these tiles provide a durable, moisture-resistant, and cost-effective response to the city's tropical climate.¹ Mosaic tiles generate textured and chromatic surfaces that contribute to the visual character of urban architecture. For ease of construction, they are commonly pre-mounted on mesh, paper, or dot backings, facilitating efficient installation and material stability.² In the local context, they are also referred to as “paper stones” (紙皮石). These tiles are practically adapted to Hong Kong due to affordability, water-resistance, and agility. They are easy to apply to the curved surfaces which enable the formation of dense, continuous surface planes and have become a ubiquitous feature across Hong Kong's architectural landscape.

Despite their prevalence, academic research has paid limited attention to rendering materials, particularly vernacular applications such as mosaic tiles, which are often discussed primarily in terms of aesthetics and cost (Liang & Xiang, 2025). This study seeks to address this gap by examining mosaic tiles as meaningful architectural surfaces within the Hong Kong context. Adopting a territory-wide perspective, it investigates their application across six building typologies: mixed-use buildings, multi-storey structures, residential developments, commercial buildings, public infrastructure, and church through a case study methodology.

¹ Building External Finishes, HA, 2020. Retrieved from <https://www.bd.gov.hk/doc/en/resources/codes-and-references/practice-notes-and-circular-letters/pnap/ADV/ADV031.pdf>

² Caivano, J. L. (2006). Research on colour in architecture and environmental design: Brief history, current developments, and possible future. *Color Research and Application*, 31(4), 350–363.

The research is conceptually grounded in Peirce's semiotic theory of signs, further developed through a three-layer semiotic framework to analyze how meaning is constructed and interpreted.³ Through this lens, the study examines the formal properties of mosaic tiles, including pattern, color, scale, and surface articulation, as systems of signification. By situating these material surfaces within their architectural, cultural, and urban contexts, the research interprets mosaic tiles not merely as functional finishes, but as communicative devices that reflect processes of cultural continuity and transformation in Hong Kong's post-war urban development.

1.2. Research Purpose

Academic research has paid limited attention to rendering materials, particularly vernacular materials such as mosaic tiles, which are often discussed only in terms of aesthetics and cost. This study aims to expand that discussion by investigating mosaic tiles as a meaningful architectural surface in the context of Hong Kong.

1.3. Research Question

The widespread use of mosaic tiles across both interior and exterior surfaces of Hong Kong's buildings prompts critical inquiry into their formal organization and cultural significance. This study asks: what compositional and spatial patterns characterize mosaic-tile façades in Hong Kong, and how do these vary across building typologies and urban contexts? Are there recurring configurations of tile placement, motif, color, scale, and surface articulation? If yes, what are the cultural and semiotic meanings embedded in these surfaces? These questions examine how mosaic-tile surfaces operate not only as material finishes, but also as visual and cultural expressions of place, identity, and urban life.

2. THEORETICAL REVIEW

2.1. Semiotic Application in Architecture

Architecture has increasingly been framed as a system of signs rather than a purely technical or functional discipline. Drawing on links with scientific thought and philosophical aesthetics, scholars use semiotics to explain how architectural forms participate in wider processes of knowledge production and cultural expression (Yu, 2014). Within this context, semiotics has been recognized as a core theoretical framework in contemporary thought, extending from philosophy into areas such as architectural theory and debates on regionalism, where it helps to analyze how globalized forms are mediated by local cultures, materials, and identities (Lipman, 1986).

³ Lai, Xu. *The Application of Architectural Semiotics in Adaptive Reuse of Chinese Vernacular Architecture*. Chapter 2.2.2., 2025.

Peirce's triadic theory of the sign—comprising Symbol (or Representamen), Object, and Interpretant—provides a key conceptual tool for such analyses (Huang and Chen, 2004). In architectural terms, the material and spatial configuration of a project can be read as the Symbol; the site, program, or broader context functions as the Object; and the meanings, associations, and readings produced in users and observers form the Interpretant. This aligns with broader semiotic work (Greimas, Groupe μ , Perelman, Hjelmslev) that distinguishes between the content plane and expression plane, and between denotative and connotative levels of meaning. Within this broad semiotic universe, architecture is treated as a connotative semiotic system (Scalvini), where buildings operate not only as shelters or structures but also as carriers of layered cultural connotations, understood through shared codes and interpretive frameworks grounded in the “science of signs” formulated since De Saussure.

The relationships among these components are presented as a triangle, commonly referred to as the “Semiotic Triangle” (Figure 1). In this model, the relationship between the “Signifier” and the “Signified”—that is, the connection between the sensible form of the sign and the object or concept it represents—must be clearly identified. “Signification” describes the process by which signifier and signified are linked to form a sign. Crucially, this linkage is not automatic: a sign can establish a connection with its referent only through the act of interpretation. Once this interpretive connection is formed, the sign points toward a particular outcome or reading, which can be understood as a deeper layer of “meaning.”

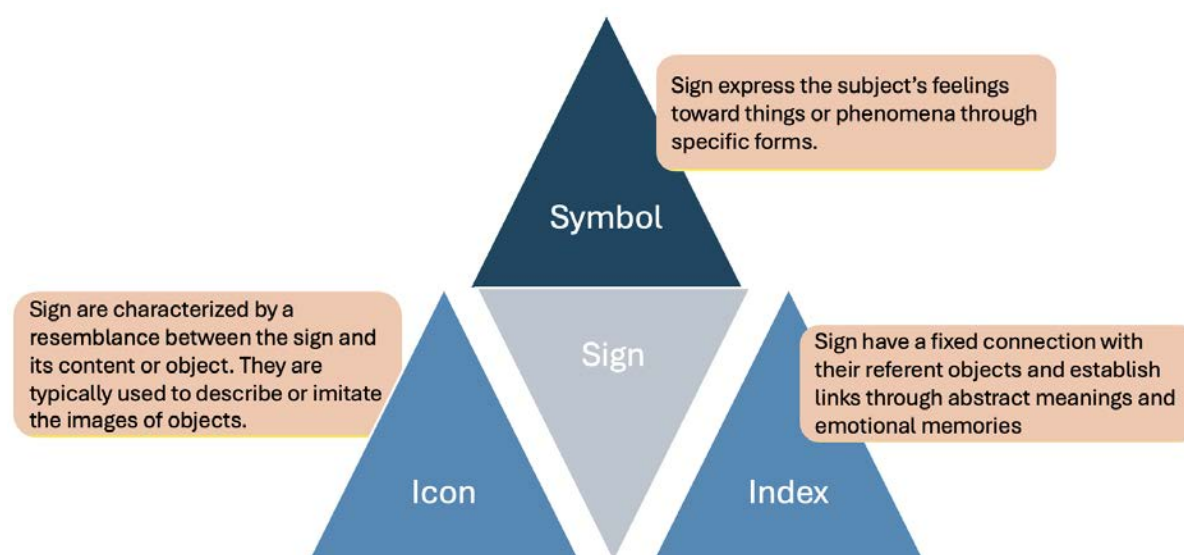


Figure 1: Peirce's modes of sign representation. (Source: Author).

2.2. Method

This study is qualitative research. With extensive photographic documentation and digitally generated vector imagery to examine the semiotic dimensions of mosaic-tile surfaces in Hong Kong. It employs a

case-study approach organized by building typology rather than geographic location, focusing on seven categories: mixed-use buildings, multi-storey structures, residential developments, commercial buildings, public infrastructure, and church. Within each typology, vector photos are generated for the clarity, legibility, and representativeness of their mosaic-tile articulation, allowing attention to both façade-scale composition and fine-grain material detail.



Figure 2. Designated sites. (Source: Author).

The interpretive framework is grounded in Peirce's semiotic theory of the sign and is operationalized through a three-layer reading of icon, index, and symbol. Within this framework, the formal features of mosaic tiles are understood as icons (where motifs bear visual resemblance to referents), symbols (where colors or patterns function through convention and shared cultural codes), and indices. In the latter sense, specific, often vibrant mosaic schemes—such as those associated with Hong Kong's MTR stations—are

read as indices of the mass transit system, pointing toward wider networks of mobility, infrastructure, and everyday urban life.

Data collection combines on-site photographic surveys with AI-assisted image processing. Mosaic-tile surfaces are recorded using phone and camera photography, capturing both overall elevations and close-up views of tile patterning, joints, and surface conditions. These images are subsequently processed through an AI-based workflow to generate vector-style mosaic representations, which are imported into Adobe Illustrator and converted into editable paths via the “Image Trace” function. The resulting clean, noise-reduced vector drawings make it possible to trace the alignment, modular ordering, and compositional logics of individual tesserae with greater precision than raw photographs typically allow. Analytically, the study follows a three-stage procedure: photographing façades, digitizing and vectorizing selected images, and then coding the resulting drawings according to pattern logic and chromatic organization. Mosaic-tile compositions are categorized by levels of complexity in both pattern and color diversity—ranging from monochrome to multicolor, and from plain surfaces to geometric or tessellated configurations. These categories are then examined in relation to building typology to explore how particular arrangements of tiles correspond to architectural identity, program, and spatial organization, as well as to the reinforcement of institutional or corporate iconography.

A key limitation of this methodology lies in the use of AI-generated vector imagery: while the process clarifies overall pattern and alignment, it is not reliable for accurately counting individual tiles or enumerating discrete pattern units, particularly where mosaics appear abstractly arranged or where boundaries between tesserae are visually ambiguous. Consequently, the analysis privileges qualitative pattern recognition and typological categorization over exact quantitative tile counts, underscoring the interpretive nature of the study and situating its findings within a visually and semiotically oriented, rather than strictly metric, account of mosaic-tile surfaces.

3. DISCUSSION

3.1. Mosaic Tile as an Icon of Post-war Building Materials

In the context of post-war building production in Hong Kong, mosaic tiles emerged as an **iconic** material, condensing within their small scale a particular synthesis of economy, performance, and visual ambition.⁴ Relatively inexpensive yet of reliable quality, they provided a thin, water-resistant surface that safeguarded exposed masonry while simultaneously offering a refined, chromatic surface suited to the density and verticality of the city’s expanding urban fabric. Introduced from Europe in the 1950s and rapidly adopted through the 1950s–60s, mosaics soon became closely associated with the architectural

⁴ *Ibid.*

language of the period, to the point where their presence now visually indexes the post-war era in Hong Kong's streetscapes.⁵

At a material and commercial level, their diffusion was supported by an emerging local industry that operated initially through “brick and tile shops” dealing in cement, sand, and Guangdong red bricks, before expanding into ceramic products. Companies such as Castle Peak Ceramic Company Ltd, with a city-center sales office and a large factory in Tuen Mun, played a key role in standardizing and disseminating mosaic tiling as a readily available cladding option. This coincided with rapid population growth and acute housing shortages, prompting the Hong Kong Government in the late 1960s to launch extensive public-housing and new-town programs. Within this mass-construction context, mosaic tiles became a dominant finish for façades, stairwells, and circulation spaces, so that the fine grain of tessellated surfaces effectively came to stand for the new modern housing estates and the promise of improved living conditions.⁶

Although mosaic tiles were more expensive than paint, their superior durability and ease of localized repair made them economically attractive over the building life cycle: if individual tesserae detached, they could be replaced selectively, at relatively low cost. At the same time, small businesses often drew on surplus or leftover “paper stones” from larger projects to finish their own interiors and shopfronts, assembling walls from multiple batches of different colors and textures.⁷ This practice of re-use and improvisation generated richly variegated surfaces—an expression of grassroots ingenuity that, over time, contributed to a distinctive everyday streetscape in Hong Kong.

From the 1980s onwards, however, the material has faced increasing challenges. After roughly three decades of exposure, mosaic-tile cladding is prone to weathering, debonding, and peeling, raising concerns about maintenance costs and safety.⁸ In response, more durable coating systems and alternative tiling technologies have progressively replaced large-scale mosaic applications on exterior façades, especially in the context of tightened waterproofing and leakage-prevention requirements. Today, the use of mosaic tiles in Hong Kong has largely shifted from extensive external cladding to more limited, often decorative interior applications, and examples of buildings that still employ “paper stone” across entire façades or flooring systems have become comparatively rare.⁹

⁵ CityMag, Z. (2025, January 10). Design Trust, Design Criticism: Why Hong Kong's Buildings Are Clad in Bathroom Tiles. Zolima City Magazine.

⁶ Hong Kong 瓷磚史. (n.d.).

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⁹ Hu, Wenchao, et al. Surface mosaic synthesis with irregular tiles. *IEEE Transactions on Visualization and Computer Graphics*, 22(3), 1302–1313, 2015.

3.2. Mosaic Tiles as Index

In design terms, mosaic tiles in Hong Kong operate as indexical surfaces: they not only decorate and protect the building envelope, but also point toward specific spatial, social, and infrastructural conditions. Affordable and convenient to deploy, mosaics offer designers a high degree of formal and chromatic freedom through a wide spectrum of sizes, colors, and textures. The combination of different hues, shapes, and materials can produce simple fields of color or highly elaborate patterns and inscriptions, effectively “painting” with small bricks. In a city where space is scarce, the small square mosaic—by far the most ubiquitous format—functions as a compact yet highly ductile graphic language, capable of compressing imagery, signage, and orientation cues into limited surfaces. Such indexical uses are evident both in outdoor applications (Figure 7) and in the interior environments of MTR stations (Table 1), where color schemes and motifs come to stand for specific lines, locations, or institutional identities, pointing beyond the surface itself to wider systems of mobility and place.

At the level of terminology and technical classification (Table 1), mosaic tiles also act as indices within the regulatory and constructional logic of Hong Kong’s façades. In professional practice, “external wall finishes” serves as a broad category for coatings, renders, and tiles applied to exterior substrates, while “cladding” designates a non-structural facing or architectural decoration added to structural elements, encompassing stone, metal, ceramic and mosaic tiling systems as one specific cladding mode. Within this framework, “wet-fixed tiles” refers to ceramic or mosaic tiles bedded into cement–sand mortar rendering, indexing a particular construction method, performance expectation, and maintenance regime.

Functionally, the external cladding system is further articulated through references to render, adhesive, grout, and the integrated “external cladding system,” foregrounding the layered, interdependent nature of backing, bonding, jointing, and surface finish. At the material register, more granular terms differentiate glass mosaic tiles, usually 19–23 mm vitreous glass tesserae commonly used on façades which denote small-format chips employed as durable external finishes, as well as “homogeneous tiles,” a local term for dense through-body tiles suitable for external exposure,¹⁰ and the distinction between unglazed and glazed mosaics, where surface treatments index different aesthetic effects, weathering behaviours, and maintenance demands. Essentially, these technical and material labels do not simply describe mosaics; they also index specific construction cultures, regulatory frameworks, and climatic responses that situate mosaic tiling as a highly charged architectural sign within Hong Kong’s built environment.

¹⁰ How Hong Kong’s MTR stations got their colours | Cathay. (n.d.). Cathay Pacific.

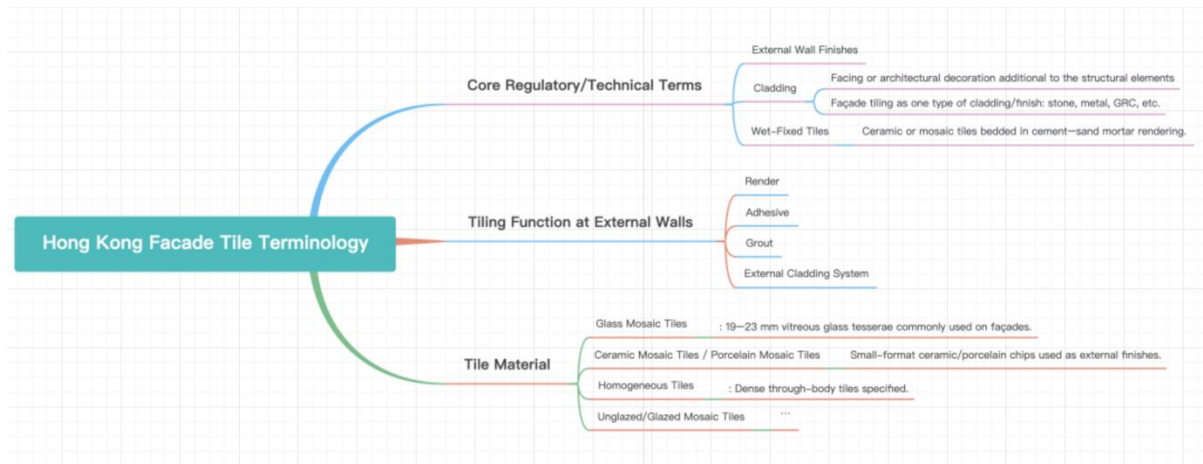


Table 1: Hong Kong Façade Tile Terminology. (Source: drawn by the author).

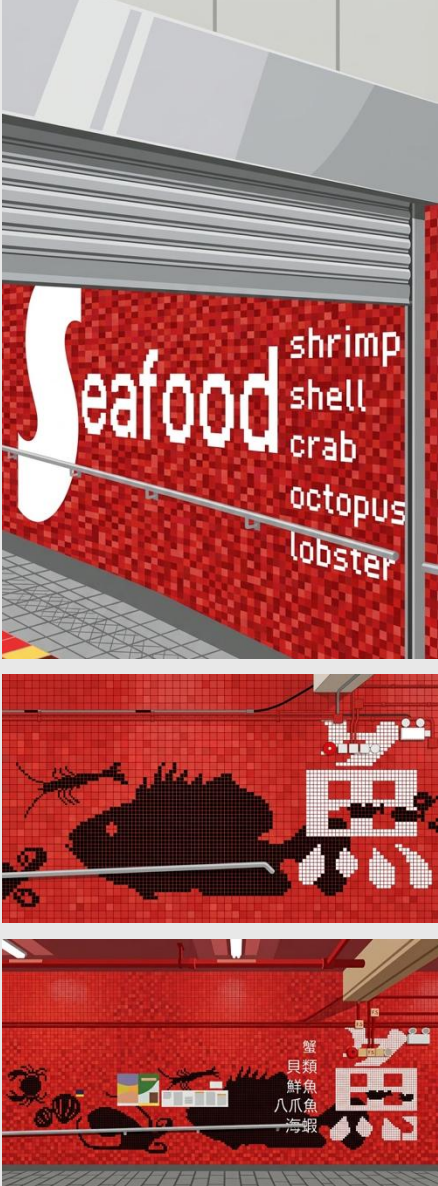
3.3. Mosaic Tiles as Symbol

Mosaic tiles in Hong Kong's everyday architecture emerge, in light of the tabulated cases, as a pervasive semiotic medium rather than a neutral finishing material, actively communicating place identity, spatial function, and cultural emphasis through color, pattern, and placement. In Tables 2 and 3, market and commercial buildings, tiled surfaces work as symbolic markers of place, translating program and branding into a stable, repeatable surface language that enables users to recognize “this market” or “this block”¹¹ even before reading textual signage. In circulation and service environments, such as multi-storey car parks, public estates, and urban parks, it is found that monochrome schemes, arrows, bands, and plain patterned fields operate as a vernacular graphic system. The use of simple design direction, zoning, and everyday functional organization in forms that users gradually learn to read and inhabit. In domestic interiors and churches, multicolored, checkered, or tessellated patterns foreground culture and ethos, materializing taste, social status, heritage, or spirituality in ways that exceed purely utilitarian finish. Transit spaces like MTR stations, exhibit the densest symbolic layering, where chromatic patterns simultaneously articulate navigation, zoning, and artistic identity, turning the tiled surface into a symbolic interface between infrastructure and user. Vector imageries shown in Table 3 allow clearer reading on the pattern arrangement of the mosaic tiles in the mentioned site. The small-format mosaic tiles shown in the two tables constitute a locally specific semiotic infrastructure through which Hong Kong's ordinary spaces make identity, function, and cultural values visually legible, and thus play an active role in constructing and reinforcing the cultural and spatial order of the city.

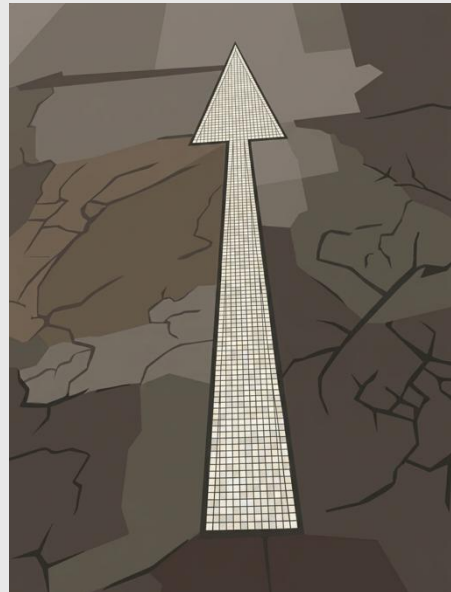
¹¹ “呢啲咁嘅紙皮石似美樂花園喎” This design pattern of the mosaic tiles reminds (me) of the Melody Garden, HK. Retrieved <https://www.threads.com/@jacksonlamf/post/DXRLiGZEr6m/呢啲咁嘅紙皮石似美樂花園喎/>

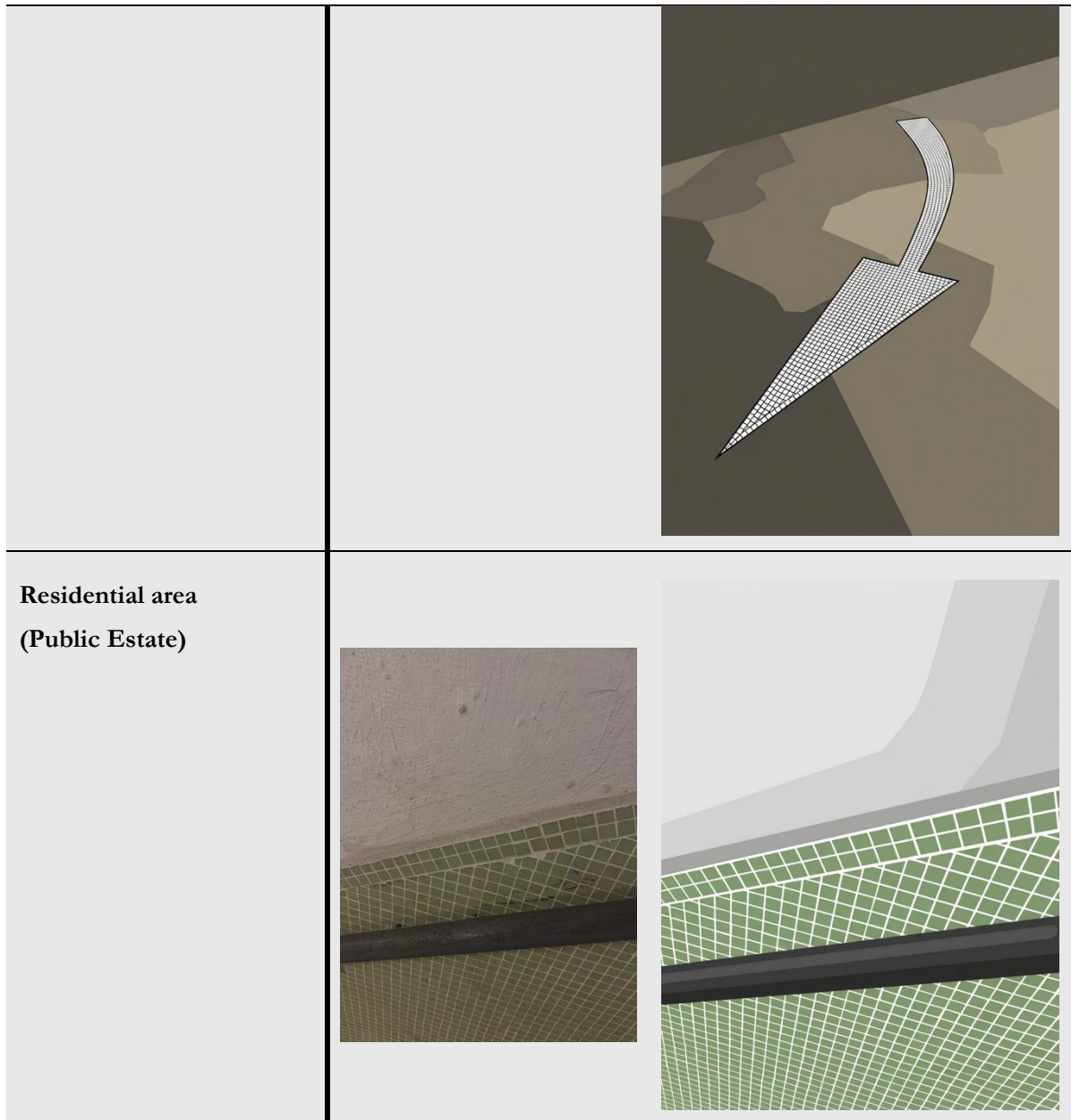
TYPOLOGIES (PLACE)	LOCATION	FUNCTION	COLOR/PATTERN/ MATERIAL TEXTURE
Mixed-use building (Yeung Uk Road Market, Tsuen Wan)	Interior wall	Place identifying zoning	Monochrome or two-tone. Graphs match with the products selling on each floor with wordings like fish, chicken, veggies etc. Glossy
Multi-story structures (Leighton Center shopping mall parking lot, Causeway Bay)	Floor	Wayfinding directing zoning	Monochrome Arrows
Residential area (Public Estate)	Exterior wall	Render	Monochrome or two-tone
Residential area (Mansions/Private Housing)	Interior decoration	Symbol of culture Surface emphasis	Multicolored with repeating pattern Checkered, tessellated
Commercial Building (Kai Tak Commercial Building, Central)	Exterior wall	Render Place identity	/
Public Infrastructure (Urban Parks)	Bench	Zoning Decoration	Plain, simple
Commercial Building (MTR stations)	Column Interior wall	Navigation Zoning Artistic creation	Mixing Chromomeric Palette
Church (The Cathedral Church of Saint John the Evangelist, Central)	Floor	Decoration	Chromomeric Palette

Table 2: Table of the usage of mosaic tiles in designated areas (Source: by author)

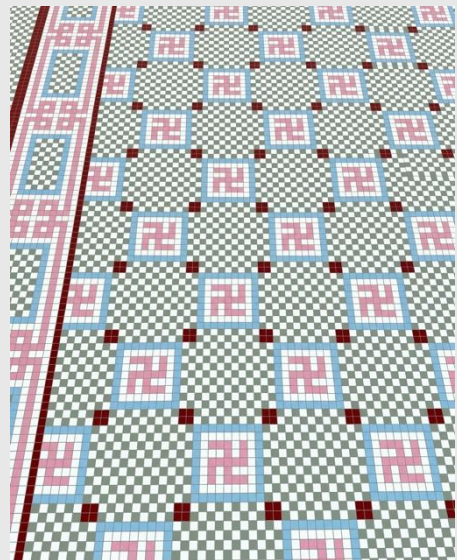
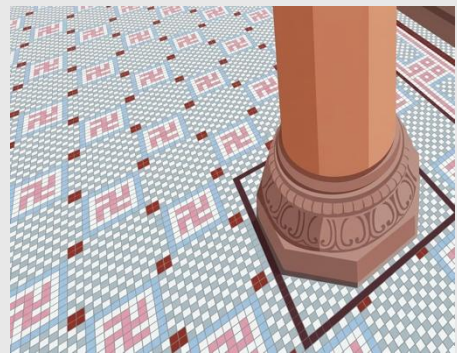
TYPES (PLACE)	SITE PHOTO	VECTOR IMAGERY
Mixed-use building (Yeung Uk Road Market, Tsuen Wan)		

**Multi-story structures
(Leighton Center
shopping mall parking lot,
Causeway Bay)**

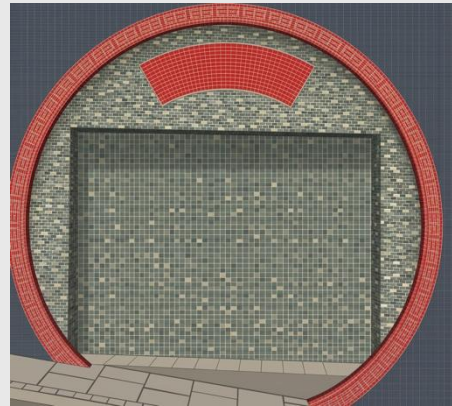




Residential area
(Mansions/Private
Housing)



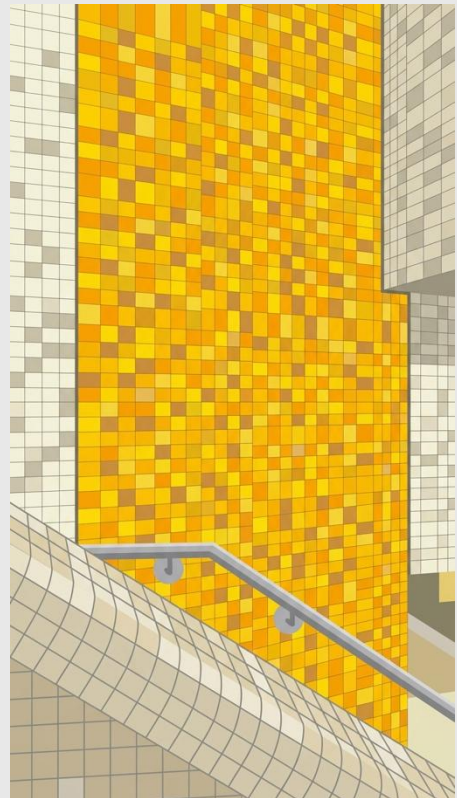
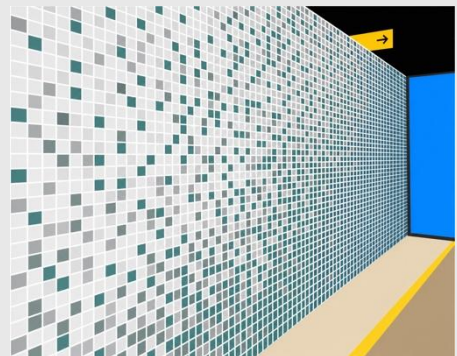
Commercial Building
(Kai Tak Commercial Building, Central
Local antique store,
Central)



Public Infrastructure
(Urban Parks)



**Commercial Building
(MTR stations)**



		
<p>Church (The Cathedral Church of Saint John the Evangelist, Central)</p>		

Table 3: Mosaic tiles in vector style in designated areas (Source: by author).

4. CONCLUSION

This paper presents a semiotic reading of mosaic tiles in Hong Kong as vernacular architectural material, arguing that these surfaces are not merely decorative finishes but carriers of culture, place identity, and historical memory. The analysis discovers that mosaic tiles operate through icon, index, and symbol, so that their pattern, color, scale, and surface articulation communicate meanings beyond function, while also reflecting the practical conditions that made them durable, affordable, and widely adopted in the city's post-war built environment. Future development should be directed toward extending the study beyond Hong Kong, comparing more building typologies and cultural settings, and refining the method by combining semiotic interpretation with more systematic documentation so that the reading of vernacular material can gain greater breadth and precision.

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Traditional Dwellings and Settlements

Working Paper Series

POCO A POCO: INCREMENTAL BUILDING AND IDENTITY NEGOTIATION IN NEW VERNACULAR ARCHITECTURE OF OAXACA DE JUÁREZ, MÉXICO

Catherine Sckerl

POCO A POCO: INCREMENTAL BUILDING AND IDENTITY NEGOTIATION IN NEW VERNACULAR ARCHITECTURE OF OAXACA DE JUÁREZ, MÉXICO



*This paper examines the poco a poco (little by little) building process in Santo Domingo Tomaltepec, a Zapotec *usos y costumbres* community in the urban periphery of Oaxaca de Juárez, México, exploring what motivates residents' building decisions beyond survival logic. Drawing on ethnographic observation between 2019 and 2025 and semi-structured interviews and house tours in July 2025, the study documents vernacular building practices and residents' accounts of their incremental decision-making. Three findings emerge from the research: that building decisions are motivated by care for family, livelihood, community and the earth; that identity and territorial claims of belonging are entangled in practice, expressed simultaneously through placemaking and placekeeping; and that the incompleteness of incremental houses reflects ongoing negotiation with uncertain futures. Together, these findings describe urban belonging as a continuous, care-motivated negotiation enacted through decades of incremental construction. The paper contributes to scholarship on vernacular architecture and informal settlements by foregrounding the temporal, relational, and care-motivated dimensions of self-building in the urban periphery.*

1. INTRODUCTION

Oscar and Carmen's house sits just a few blocks from the village square in Santo Domingo Tomaltepec, a Zapotec *usos y costumbres* community of 3,500 residents located within the growing urban periphery of Oaxaca de Juárez, Mexico, approximately 13.5 kilometers (8.5 miles) from the city center. Historically comprised of adobe houses arranged around courtyards supporting agricultural family life, in recent decades the village has seen a wave of new construction that includes concrete and concrete-block houses, many of which adopt urban (or suburban) residential forms and reflect more contemporary lifestyles.

In his late 40s, Oscar was born and raised in Santo Domingo Tomaltepec; Carmen, in her early 40s, is from the coast of Oaxaca. They decided to settle near Oaxaca de Juárez for economic opportunities and operate a barbershop together, purchasing this plot of land in 2000. (Although Oscar's family has land in this village, the inheritance passed to his brothers; because he is native to the community, he may purchase property.) With income from their business, they have been able to incrementally invest in their house over more than two decades, a pattern common among families building in the urban periphery. Yet their decision to settle in this village brings with it obligations to the community and earth that make it distinct from other peri-urban houses.

The first phase of construction began in 2004 and included a ground floor with a living room, kitchen, dining room, bedroom, a bathroom, and two *locales* (shops) adjacent to the street. Oscar and Carmen ensured that the front façade and the shops – one a *bodega* (rented out) and the other the barbershop where they work – were completed first, including brightly painted walls, tiled floors, glass windows, and metal doors. To

accommodate their growing family, they began adding a second story in 2012, with three bedrooms, a bathroom, and a covered sleeping porch.

While Carmen says her favorite place in the house is the living room, she also spends a great deal of time in her garden at the rear of the property. Here, she has assembled plants native to the arid *Valles Centrales* as well as the tropical region where she grew up. She is especially proud of two tall fan palm trees, which she brought from the coast as seedlings; she says, “I brought them myself, because they are from my land, from Puerto Escondido.”¹ As she names each plant, fruit, and herb in her garden, she explains its origin – from the river, the coast, and the village dams – and how it is used for traditional cooking or medicines.

Much of the house itself remains unfinished: the kitchen lacks cabinets, the walls are unpainted, the floors are raw concrete, windows are missing, the sleeping porch is used for construction materials storage, and metal rebar is left exposed. Of the bedrooms, only one – for their youngest daughter – is finished with bright pink and purple paint, a sliding glass window, and built-in cabinetry. As Carmen guides me through their house, she explains: “Here is another room that still needs finishing; here is the terrace, that still needs work, too... It’s a process, *poco a poco*. It’s quite a lot we haven’t finished. It still isn’t done.”²

Oscar and Carmen’s house is representative of many houses within Oaxaca de Juárez’s urban periphery. Built *poco a poco* (little by little) over decades, it has been adapted, expanded, and modified at many moments in time. It is both comfortably inhabitable and perpetually incomplete. With each phase of investment, families like Oscar and Carmen’s engage in practices of claiming belonging across multiple dimensions, including class aspirations; responsibilities to kin both past, present, and future; heritage across geographies; and membership in an urban, peri-urban, or village community.

The *poco a poco* process of constructing houses offers a material and temporal framework through which residents co-constitute identity and territorial belonging within the urban periphery. As families add rooms, modify facades, or incorporate new materials over time, the incremental changes reflect evolving relationships to place, community, and the broader city. Belonging is negotiated continuously, in relation to others and within the constraints that shape each phase of construction, across decades of *poco a poco* building.

Scholarship on residents establishing themselves within growing urban peripheries tends to focus on economic or legal constraints, explaining when and how much families build. This framing, however, overlooks the myriad other decisions that self-builders make and forecloses alternative motivations and

¹ Carmen, interview by author, July 15, 2025. “Yo me les traje, porque es de mi tierra, es de Puerto Escondido.”

² Carmen. “Aquí es otro cuarto que falta por terminar; aquí esta la terraza, tambien falta modificación... Como es poco a poco. Bastante si no terminamos; todavía no se termina.”

rationales. Care-based decision-making and practices of placemaking and placekeeping emerge from resident accounts of Oaxaqueños building their homes. Additionally, resident stories demonstrate that territorial (legal/land) claims and identity claims of belonging are entangled, furthering the need for more holistic conceptualizations. Scholarship that solely focuses on survival both flattens and discounts ways that cities are actively constructed through residents' everyday and incremental choices.

The vernacular, self-built houses are a rich medium through which to explore how residents continually negotiate their belonging to the city, and attending to the *poco a poco* process is essential to this exploration. This paper establishes the context of Santo Domingo Tomaltepec and Oaxaca de Juárez's urban periphery, develops a theoretical framework for understanding incremental building as processual belonging, and presents findings from resident accounts of building their homes little by little.

2. THEORETICAL FRAMEWORK

Leading scholars of vernacular architecture, such as Paul Oliver and Marcel Vellinga, have emphasized that their research valorizes architectural traditions and forms of knowledge that mainstream scholarship overlooks. In his early work, Oliver established a theoretical approach that conceptualizes vernacular architecture as a self-built artifact of, and therefore inseparable from, society.³ Contemporary scholars like Vellinga endorse this holistic framing, advocating for scholars to move beyond object-only or technical understandings to situate vernacular construction within its broader context.⁴ Vellinga recognizes the dynamic nature of vernacular architecture, emphasizing that people may adapt or modify their building forms according to changing needs, which range from economic to social and from material to cultural: vernacular architecture is a form of living heritage that is not static or fixed. However, scholarship on vernacular architecture and traditional settlements tends to exclude contemporary practices of self-building in the urban periphery.

Scholarship on peripheral urban growth largely conceptualizes self-built houses in the urban periphery as pragmatic devices for survival, explaining *when* families build, while setting aside the broader question of *what* residents choose to build, and *for whom*. For example, early scholarship by John C. Turner and Robert Fichter and more recent scholarship by Alan Gilbert and Peter Ward argue that incremental houses are part of a family's economic and legal strategy for gaining access to the city.⁵ Indeed, exploring how communities

³ Paul Oliver, *Shelter and Society: Studies in Vernacular Architecture*, 1st ed. (Frederick A. Praeger, 1969).

⁴ Marcel Vellinga, "Living Architecture: Re-Imagining Vernacularity in Southeast Asia and Oceania," *Fabrications* 30, no. 1 (2020): 11–24, <https://doi.org/10.1080/10331867.2020.1721062>.

⁵ John F. C. Turner and Robert Fichter, eds., *Freedom to Build* (Collier Macmillan Ltd, 1973); Alan Gilbert and Peter M. Ward, *Housing, the State and the Poor: Policy and Practice in Three Latin American Cities*, Reissue edition (Cambridge University Press, 2009).

strategically navigate formal and informal systems created by the state has proven productive for many urban studies scholars.⁶ Critically, however, scholars like Yiftachel also call for more holistic explorations of urban belonging that extend beyond legal citizenship to include communal and cultural identity (Yiftachel 2009). Probing the strategic expressions of identity within the material environment of emergent settlements presents an opportunity to develop more holistic understandings of belonging within the city.

This paper draws on placemaking and placekeeping as complementary analytical concepts for understanding how residents negotiate belonging through the built environment. Placemaking, as theorized by Dolores Hayden and Setha Low, is the process through which residents actively shape their environments, imbuing spaces with meaning, fostering shared social relations, and demonstrating agency as they assert belonging through material and spatial interventions.⁷ For communities negotiating belonging within urban contexts, placemaking is a strategic practice, where residents creatively claim belonging to urban territory and identity through everyday building practices that establish their presence and membership in the city. Placekeeping can be understood as a specific orientation within placemaking, and focuses on practices that facilitate the long-term maintenance of “the social and environmental qualities of place for the benefit of present and future generations.”⁸ Though placemaking tends toward more forward-looking and creative practices, placekeeping is more protective, concerned with sustaining existing cultural meanings, social relationships, and environmental conditions against displacement or erasure. The incremental building process illustrates that these practices are entangled: a single material choice can assert new belonging and protect existing cultural continuity at the same time.

Scholarship on both vernacular architecture and informal settlements recognizes that building is an ongoing process, shaped by changing social, economic, and material conditions. The incremental – or *poco a poco* (little by little) – building process serves as a temporal record of choices that families make over time in relation to a changing context. Importantly, *poco a poco* building is practiced across economic levels, not only among the poorest households, further suggesting that survival-logic frameworks are insufficient to account for the full range of motivations at work. As families add rooms, modify facades, or incorporate new materials, their choices reflect and contribute to evolving negotiations of place, community, and urban belonging. Attending to the *poco a poco* process adds a temporal layer to this framework, substantiating identity negotiation as an ongoing and dynamic practice. This paper also draws on care ethics, which Joan Tronto defines as practices

⁶ Brodwyn Fischer et al., eds., *Cities from Scratch: Poverty and Informality in Urban Latin America* (Duke University Press Books, 2014); Oren Yiftachel, “Theoretical Notes on ‘Gray Spaces’: The Coming of Urban Apartheid?,” *Planning Theory* 8, no. 1 (2009): 88–101; Faranak Miraftab, “Insurgent Planning: Situating Radical Planning in the Global South,” *Planning Theory* 8, no. 1 (2009): 32–50, <https://doi.org/10.1177/1473095208099297>.

⁷ Dolores Hayden, *The Power of Place: Urban Landscapes as Public History* (The MIT Press, 1995); Setha Low, *Spatializing Culture: The Ethnography of Space and Place* (Routledge, 2017).

⁸ Summer Gray, *In the Shadow of the Seawall: Coastal Injustice and the Dilemma of Placekeeping*, 1st ed. (University of California Press, 2023), <https://doi.org/10.2307/ji.5699311>, 3.

oriented toward the maintenance and continuation of relationships, with family, community, and the world one inhabits.⁹ By foregrounding the *poco a poco* process of vernacular building, this research finds that construction in Oaxaca de Juárez is often motivated by care for family, livelihood, and community, even as economic, legal, or practical constraints shape the conditions within which those choices are made.

3. METHODOLOGICAL APPROACH

This paper draws on a larger research project that employs qualitative methods combining historical research, ethnographic observation, and semi-structured interviews to document and interpret emergent vernacular architecture in Oaxaca de Juárez's urban periphery. For this paper, self-builders are owner-occupiers who direct the construction of their own homes; while they may employ professional builders or master masons, the work is undertaken for their own use and occupancy.

The methodological approach is interdisciplinary and oriented toward decolonial research principles that center and valorize knowledge about the city and ways of knowing that are typically overlooked by architecture and urban planning scholars. Ethnographic fieldwork has been conducted across multiple visits to Oaxaca between 2019 and 2025, accumulating approximately six months of time in the field. Fieldwork has focused on structured neighborhood walks and architectural observation in Santo Domingo Tomaltepec and two additional peripheral areas – San Felipe del Agua and Pueblo Nuevo – producing photographs, fieldnotes, and sketches. Multiple years of fieldwork enabled longitudinal observation of architectural patterns and changes while also building local relationships that made the subsequent interview phase possible.

The primary empirical basis for this paper is a phase of semi-structured interviews conducted in July 2025, following IRB-approved protocols and informed consent procedures. Seventeen formal interviews and house tours were recorded and transcribed, supplemented by additional informal conversations documented in fieldnotes. Semi-structured interviews were complemented by participant-led house tours and participant-provided photographs or sketches; this approach treated residents as authoritative interpreters of their own architectural choices, positioning their accounts as knowledge that is centered within the research. Interview data has been organized into case files for individual houses, combining transcriptions with visual and spatial documentation, and analyzed using a flexible, abductive coding approach that moves iteratively between resident accounts, ethnographic observations, and historical context. All translations from Spanish to English in this paper are the author's own, and interview participants are identified by pseudonyms. The

⁹ Joan Tronto, *Moral Boundaries: A Political Argument for an Ethic of Care* (Routledge, 2020), <https://doi.org/10.4324/9781003070672>.

interpretations offered in this paper are preliminary and will be further developed and refined through ongoing analysis.

4. CONTEXT: SANTO DOMINGO TOMALTEPEC AND OAXACA'S URBAN PERIPHERY

Oaxaca de Juárez is a mid-sized Mexican state capital of approximately 750,000 residents, internationally celebrated for its Indigenous cultures, gastronomic traditions, and UNESCO-designated landmarks. The city's official architectural heritage is anchored by *cantera verde* stone, colonial baroque façades, and pre-Hispanic landmarks including Monte Albán and Mitla; these architectural references have been celebrated by state and federal institutions since the early 1900s and more actively promoted as world heritage since the 1980s. The official heritage discourse centers on the city's historic core, establishing a visual and architectural language that residents across the urban periphery actively engage with, adapt, and reference in their own building practices.

Beyond the historic center, Oaxaca de Juárez has experienced significant urban expansion since the 1970s, and its metropolitan area has grown to encompass numerous surrounding villages and municipalities. The growth has been uneven: while some peripheral areas have been formally incorporated into the city's administrative structures, others – including many Zapotec and Mixtec *municipios* in the Tlacolula, Etlá, and Ocotlán valleys – retain their own governance structures and land tenure systems while becoming increasingly integrated into the metropolitan area. This paper examines the vernacular building practices within these peripheral areas, which are neither fully rural nor fully urban, and in which most of the region's residential construction now occurs.

Santo Domingo Tomaltepec, the primary case site for the research presented in this paper, is a Zapotec *municipio* of about 3,500 residents located approximately 13.5 kilometers (8.5 miles) east of Oaxaca de Juárez's historic center in the Tlacolula Valley. With pre-Hispanic origins and a colonial-era urban plan organized around a church and government plaza, the community has maintained its identity as a distinct village governed under *usos y costumbres* – an Indigenous governance system that regulates land tenure and building practices, prescribes community service obligations, and retains collective decision-making outside party political structures. Land in Santo Domingo Tomaltepec does not enter the typical real estate market: land may be privately held, but it may only be inherited within families or acquired by people with established community ties. The *usos y costumbres* governance structure is common in Oaxaca's urban periphery, though each *municipio* has unique practices.

The community of Santo Domingo Tomaltepec has grown steadily from approximately 1,552 residents in 1970 to approximately 2,367 in 2000; growth over the last two decades has brought the population to 3,386.¹⁰ To accommodate increased population, the village has both densified its historic core and experienced horizontal expansion into agricultural lands at its periphery. New construction has accelerated over the past twenty years, producing a landscape in which adobe houses of varying ages (some centuries old) sit alongside concrete and brick additions, second stories, and entirely new buildings. This emergent built landscape is the site of the vernacular building practices, material choices, and identity negotiations documented in this paper. It is also a built landscape that official heritage discourse has largely overlooked because it does not conform to the visual languages that Oaxaca's heritage institutions have identified as worthy of recognition.



Figure 1: In recent decades, Santo Domingo Tomaltepec's urban footprint has expanded outward, placing pressure on the surrounding agricultural lands. (Source: Catherine Sckerl, 2025).

¹⁰ Instituto Nacional de Estadística y Geografía, 2015 *Sociographic and Economic Indicators for Oaxaca, Mexico* (INEGI, 2015), <http://en.www.inegi.org.mx/app/areasgeograficas/?ag=20>.



Figure 2: The *municipio* has been undertaking street upgrading projects, which pave the roads and upgrade services. (Source: Catherine Sckerl, 2025).

5. FINDINGS: BUILDING *POCO A POCO* (~3000W)

The following findings draw on resident accounts of building poco a poco in Santo Domingo Tomaltepec. Three interconnected themes emerge. First, building decisions are motivated by care for family, livelihood, and community; this care operates within economic and legal constraints but is not reducible to them. Second, identity and territorial claims of belonging are entangled in practice, expressed simultaneously through placemaking and placekeeping. Third, the incompleteness of incremental houses reflects an ongoing negotiation with uncertain futures.

5.1. Strategic, Care-Motivated Sequencing

During each phase of construction, residents in Santo Domingo Tomaltepec make a myriad of decisions in relation with a dynamic contemporary context. These choices are made in relation to others and in response

to changing circumstances, revealing *poco a poco* is strategic practice. Families in this pueblo navigate government rules and regulations, economic opportunities and constraints, and technological and material changes alongside land inheritance dynamics, responsibilities to ancestors, kin, and the earth, and personal needs and preferences. While *when* to build may be primarily governed by economic constraints, families' choices about *what* and *how* to build reflect deliberate, relational and adaptive decision-making that is underpinned by care for family, livelihood, and community. The poco a poco process reveals these moments of individual agency, unfolding over time as residents work to build their houses and neighborhoods.

Oscar and Carmen's case illustrates how care underpins decision-making during each phase of construction. Their house phasing reflects a combination of pragmatism, achievement, and aspiration: the first phase of construction prioritized spaces that provide financial stability for the family, completing the bodega and barbershop before the living spaces. Oscar and Carmen expanded their house as their children grew, adding private bedrooms, baths, and a terrace on an upper level. While Oscar says they would have preferred adobe if not for cost, Carmen says the house's design inspiration is urban "residencial," signaling their middle-class positioning within this growing urban periphery. Yet Carmen also chooses to nurture and propagate garden plants that represent their mixed Oaxacan heritage, and she incorporates these vegetables, herbs, and fruits into homemade traditional dishes. Each phase captures the complex, relational, and adaptive decision-making underpinned by care, poco a poco.

Located in a formerly agricultural edge of the village, Orlando's strategic choices about his house are also underpinned by care for his family. Orlando is a third generation *panadero* (breadmaker) from Santo Domingo Tomaltepec, whose profession is woven into both his house and his village's identity. When he acquired this empty plot of land (from his mother's inheritance), Orlando constructed the bakery's *horno* (oven) and *taller* (workshop) spaces first, prioritizing productive spaces as a way to sustain his family. Five years passed before any living or sleeping areas were constructed. For Orlando, breadmaking is more than just a source of employment: it is a way of living that connects him to his father and grandparents, as well as the village itself, whose annual Feria del Pan each April centers breadmaking as an expression of community identity. The interior of the storefront where he sells his bread is painted a deep golden yellow, the color of *pan de yema*, a traditional egg-yolk bread local to the region; visible from the street, this color announces what is being sold, who the family is, and where they come from. Today, the house accommodates both enterprise and family life: the bakery's production spaces share the property with a living area, kitchens, and bedroom spaces. Orlando has plans for a second story, including bedrooms for his two growing boys, and imagines a rooftop *pizzería* (pizza restaurant) with views of the surrounding mountains. While this addition remains unbuilt, the exposed rebar and Orlando's vision hold this future open, to be built poco a poco.

Just down the street, Paula and Elmer's house and *carnicería* (butcher shop) tell a similar story. As a younger son, Elmer received no inheritance – everything they have, including the land, they earned for themselves. About twenty years ago, Paula and Elmer built the *carnicería* storefront and the main house together in one phase. A few animal pens at the rear of the property suggest the more expansive agricultural operation – hogs and cattle raised on a separate parcel – that forms the family's primary livelihood: the *carnicería* serves as an urban face of this larger business. The house has expanded outward and upward in subsequent phases as funds permitted, though many of the rooms lack finishes. Paula describes their strategic decision-making plainly: "We have the expenses of the house, the children, school and everything else – and the government doesn't help us 100%."¹¹ Saving where possible, she and Elmer directed their resources toward what the family needed most. "We decided it was better to build three more rooms and a bathroom upstairs for the children," she explains.¹² In other words, the paint could wait, but the children's bedrooms could not. "It's like this, *poco a poco*," Paula says of the process with a laugh, "but that's just how we will continue."¹³

For Elena and Ricardo, two lifelong residents of Santo Domingo Tomaltepec who work as a schoolteacher and social worker, respectively, the *poco a poco* process also yields moments for reflection and learning: choices made during one phase of construction – in response to circumstances and aspirations at that point in time – may no longer serve contemporary needs. Elena and Ricardo's house, which was originally comprised entirely of adobe structures, was inherited through Ricardo's mother. When replacing some of the older rooms, they chose to build in concrete because they considered it more structurally safe for their family during earthquakes. Concrete was also more economically affordable. Today, however, Elena has regrets: she wishes that they would have rebuilt with adobe and left more of the ground unpaved. "Why?" I ask. She turns reflective, "Because we are destroying what little we have left, which is Nature."¹⁴ Elena explains that the concrete causes the water to run away and makes the earth hotter, which – in turn – makes it difficult to maintain traditional agricultural and gastronomic practices central to her family's way of life. Her regrets are rooted in care for the land, for the practices her daughters may inherit, and for a community whose relationship to the earth she believes should be protected. Elena's case shows that *poco a poco* building is also a reflective practice: as they incrementally add to their houses, residents also build experience and awareness of what earlier decisions cost.

Across these four cases, economic constraint shapes the pace and scale of building, often determining when families build and how much they invest, but care governs the priorities within each phase, determining what

¹¹ Paula, interview by author, Santo Domingo Tomaltepec, July 11, 2025. "Tenemos los gastos de casa, hijos, escuela y todo también. Y aquí pues no nos ayuda el Gobierno al 100."

¹² Paula. "Pues y mayor obvio, obtuvimos por hacer este arriba otros tres cuartos y un baño para los hijos."

¹³ Paula. "Igual así poco a poco, pero pues ya hasta ahí nos vamos a quedar."

¹⁴ Elena, interview by author, Santo Domingo Tomaltepec, July 10, 2025. "Porque estamos acabando con lo que nos queda que es la naturaleza."

they choose to build, and for whom. This care-based motivation simultaneously operates across scales and in different directions: toward livelihood (Oscar and Carmen's barbershop, Orlando's oven), toward children (Paula's extra bedrooms, Oscar's daughters' rooms), toward heritage and community identity (Orlando's golden-yellow storefront, Carmen's Oaxacan garden), and toward the earth itself (Elena's regret about building in concrete). Together, these cases establish care as a motivational framework that is legible across varying family structures and economic circumstances. The *poco a poco* process makes these decisions visible: because choices accumulate over time and in relation to changing circumstances, the temporal record of the house shows what residents were caring for at each phase of construction.

5.2. Placemaking and Placekeeping through Incremental Building

Santo Domingo Tomaltepec shows clear signs of urbanization: the village has expanded outward and begun to densify as its population grows. Agricultural uses once welcome throughout the village have been pushed to the perimeter, and organ cactus or *carrizo* (reed) enclosures have given way to continuous brick or concrete walls. Houses like Elena and Ricardo's, which once were solely comprised of single-story adobe rooms, now feature second floors of concrete; large, single-family homes resembling suburban houses dot the landscape; and sleek contemporary aesthetics live alongside traditional stone and adobe. In recent years, the municipal government has installed concrete bridges and paved the streets beyond the central *zócalo* (square), demonstrating both the community's changing expectations as well as its integration into the broader metropolitan area.

As residents build *poco a poco*, their architectural choices simultaneously construct identity and territorial claims of belonging. Materials, forms, and aesthetics carry distinct meanings that residents strategically deploy to express relational belonging or connection with their broader community. These expressions may signal membership in the pueblo, city, or region; express heritage or modernity; convey class or indicate international connections; or assert creativity and individuality. These claims for identity and territorial belonging are entangled in practice: residents do not make one kind of claim at a time. As they build, they simultaneously engage in placemaking and placekeeping, often within a single material choice.



Figure 3: A typical, 50-year old adobe house in Santo Domingo Tomaltepec, which features a stone base and clay-tile roof, has been carefully maintained; the adjacent structure in concrete and metal was added in recent years. (Source: Catherine Sckerl, 2025).

5.2.1. Adobe

Adobe, one of the most prevalent architectural materials in Oaxaca's *Valles Centrales*, carries layered, relational, and dynamic associations for residents: it is considered precious heritage material yet expensive to maintain; thermally comfortable yet seismically vulnerable; once ubiquitous, now increasingly scarce. These complex associations shape how adobe functions in placekeeping and placemaking practices in Santo Domingo Tomaltepec.

Gabriela, an entrepreneur in her mid-30s who lives in a house that contains both adobe and concrete rooms arranged around a central courtyard, identifies adobe as part of the “essence of the town,” intrinsic to local heritage and village identity in Oaxaca. For Gabriela, adobe construction is part of what defines traditional Oaxacan villages, declaring, “What’s traditional of Oaxaca’s villages are adobe buildings.”¹⁵ When I ask her

¹⁵ Gabriela, interview by author, Santo Domingo Tomaltepec, July 17, 2025. “Lo tradicional de los pueblos de Oaxaca son las construcciones de adobe.”

whether it should be preserved, she responds emphatically: “It’s important to preserve the tradition of adobe construction. Because, in a way, the identity doesn’t disappear, right? How can we lose the essence of the town? Urbanization arrives and everything is lost: customs are forgotten, traditions are forgotten, even trades are forgotten. So it would be good if we could preserve that design.”¹⁶ For Gabriela, adobe materially connects community identity and pueblo space, making identity and territory claims inextricably linked in the material itself. She frames adobe preservation as a collective responsibility, referencing design codes in other communities and Zapotec language instruction in schools as parallel efforts: architectural heritage and cultural heritage require the same active, community-wide commitment.

Yet Gabriela’s commitment to preservation is limited by economic and pragmatic reality. She is the caretaker of two properties that contain adobe structures and is faced with difficult decisions about their maintenance. The more centrally-located property where she lives with her parents is lovingly maintained. A second property located two blocks away and made entirely of adobe buildings, is abandoned and crumbling. After heavy rains destroyed its main structure three years ago, Gabriela’s family carefully saved the century-old bricks, setting them aside for future rebuilding. However, Gabriela is uncertain about this property’s future and grieves its potential loss. Comprehensive adobe restoration is cost prohibitive, especially for an uninhabited property. The compound represents what Gabriela articulates should be preserved (“the essence of the town”), but contemporary economic constraints make this type of upkeep impossible. Her two properties illustrate one of placekeeping’s central tensions – that collective values encounter individual limits – as well as a sobering corollary – that cultural loss also occurs *poco a poco*.



Figure 4 & 5: Cantera verde stone and cantera verde colored paint surround gates in Santo Domingo Tomaltepec. (Source: Catherine Sckerl, 2025).

¹⁶ Gabriela. “Entonces, creo que es, es importante preservar el tema de la construcción de adobe. Porque de alguna forma no se va la identidad. ¿No? Y tampoco como perder la esencia del pueblo. Llega la urbanización y se pierde todo. Se olvidan costumbres, se olvidan tradiciones, se olvidan incluso oficios... Entonces, estaría bien que se pueda preservar ese diseño.”

5.2.2. Cantera Verde

Throughout the *Valles Centrales*, stone – and especially locally quarried *cantera verde* – is one of the most commonly employed materials in both historic landmarks and contemporary construction. The prevailing recognition of cantera verde as the signature material of Oaxaca de Juárez shapes how residents across the urban periphery deploy the stone to claim belonging to broader Oaxacan identity, though many residents hold their own understandings of cantera's regional geography and symbolic importance. In the periphery, cantera verde appears throughout houses of every style, age, and economic level. Deployed prominently on street-facing façades – as an expansive field of color, framing gateways or front doors, or paired with brick – it appropriates prestigious aesthetics from the city center for vernacular use in the periphery. Quarried stone is relatively expensive, making it a prestigious material deployed strategically in areas most visible from the street. For many residents, incorporating real stone into the façade is cost prohibitive; instead, they replicate cantera verde's appearance with a light blue-green paint, sometimes applied atop faux stone. In using paint as a proxy for stone, residents claim belonging through color rather than material, demonstrating that cantera verde's symbolic associations supersede material authenticity. The painted version stakes the same territorial and identity claims: belonging to the Valles Centrales, connection with regional heritage, and association with the colonial city center.

Paula and Elmer's house exemplifies this practice. The street-facing façade is rendered in the distinctive light-green color, and the walls surrounding the main gateway are further adorned with faux stone texture cast in concrete. When asked why they chose this color, Paula responds: "It's because there is a stone that is this color; the cantera is a green color. The cantera is typical of Oaxaca."¹⁷ She continues explaining, "The master mason from Mitla, well, driven by his mason's curiosity to replicate it, he went ahead and did just that. It's made of cement now, [and] they cast it using molds taken from the stone itself. Indeed, it looks exactly the same, right down to the color."¹⁸ The mason brought his own regional knowledge to the project, but the meaning behind the identity claim is Paula's.

Iliana, a schoolteacher in her early 50s, makes this point more directly. Twenty years ago, she upgraded her property's entryway, replacing a smaller brick-framed door with a broader gateway of cantera verde stone and concrete columns, which surround a teal-green metal gate. Her explanation is direct: "For my home state, cantera is always the reference point... Cantera stone is an integral part of Oaxaca, it's something that we

¹⁷ Paula, interview. "Es que hay una piedra que es este color, la cantera es color verde. La cantera es típico de Oaxaca."

¹⁸ Paula. "El maestro albañil, lo de Mitla, o sea, de su curiosidad de albañil imitarlo, pues y ya lo hace, es cemento, ya le sacan las... es de la piedra, si eso es igual, al mismo [color]."

really identify with.”¹⁹ She frames the choice as modern rather than traditional, stating, “It’s beautiful and we should break away a little from the strictly traditional style.”²⁰ She positions cantera on the façade as a claim to urban belonging rather than village heritage. Together, Paula and Iliana’s cases show that cantera verde operates as a shared regional identity marker across the periphery: residents independently make similar material choices, producing a collective visual language that stakes territorial and identity claims simultaneously.

Adobe and cantera verde are not the only materials carrying layered and relational meanings. Brick, introduced during Spanish colonization, works at a national Mexican scale, and is frequently combined with cantera to layer regional and national Mexican heritage claims or is deployed in decorative, textural patterns to signal design ambition and class aspiration. Concrete, ubiquitous in contemporary construction, stakes modernity and urban belonging claims while also addressing seismic safety concerns, which residents articulate as being essential for family. Corrugated metal, glass, wood, tiles, and ironwork complete the material palette, each carrying its own functional purpose and symbolic meaning. Together, these material choices show that residents are navigating multiple scales of identity and territorial belonging simultaneously, often within a single façade: pueblo Zapotec, regional Oaxacan, national Mexican, modern/urban, or traditional/village. The self-built houses materialize these layered negotiations: as residents build *poco a poco*, each phase of construction is an opportunity to position themselves relationally, making choices that express heritage and aspiration, tradition and modernity.

The cases explored in this section demonstrate that placemaking and placekeeping are simultaneous, entangled practices through which residents co-constitute identity and territorial belonging. Adobe, cantera verde, brick, and concrete carry layered meanings that residents deploy strategically to (re)position, articulate, and represent themselves relationally across scales of the pueblo, city, and region; between heritage and modernity; and with obligations to ancestors, kin, community, and the earth. The *poco a poco* process illuminates that these negotiations accumulate over time, shaping a dynamic and collectively produced urban fabric.

¹⁹ Iliana, interview with author, July 16, 2025. “Por mi estado que siempre como que la referencia es la cantera. Por lo que Oaxaca sí es con la cantera, es como que nos identificamos también.”

²⁰ Iliana. “Se ve bonito y hay que salir un poco de lo tradicional, de todo eso.”



Figure 6 & 7: Century-old adobe bricks are carefully set-aside and reserved for future use in Santo Domingo Tomaltepec. (Source: Catherine Sckerl, 2025).

5.3 Temporal Openness and Uncertain Futures

Even as residents build toward futures they envision, larger forces are actively reshaping what those futures may hold. Economic pressures have drawn many young people away from Santo Domingo Tomaltepec, creating uncertainty about whether the next generation will return to fulfill community obligations or inherit family properties and trades. Urbanization has brought new neighbors and more development, putting pressure on the remaining agricultural lands, and climate change has produced prolonged droughts and shifting rainfall patterns that threaten traditional agricultural and gastronomic practices. Modernization has introduced new technologies and preferences, and the building choices that residents make as they urbanize – paving patios, replacing adobe with concrete – can accelerate environmental losses. Within this context of social and environmental uncertainty, building *poco a poco* also means holding space for futures that can no longer be assumed.

Oscar and Carmen built extra bedrooms for their daughters, two of whom now live in the United States. “Do you think they’ll return?,” I gently ask. “Yes,” Oscar responds, a bit apprehensively. “They are going to come back, but they also have a different mindset, you know. We were just talking about it, how they long for the ways of the past, wondering why things aren’t done the way they used to be, because we’ve adopted practices that have absolutely nothing to do with our own customs, our culture. And that obligation – the debt to the community – it’s a good thing that they think that way, too. They are young people who are still growing up... And someday it will be their turn to give service to the community; they can certainly channel that

[perspective] into their own contributions.”²¹ Smiling, Carmen remarks, “It’s funny, isn’t it?”²² Their daughters are living in the United States and adopting more contemporary lifestyles, yet they crave a return to more traditional ways of living, of how things used to be. The irony, of course, is that the village is changing and those traditional practices may no longer exist by the time they return.

Orlando, meanwhile, imagines building a rooftop *pizzería* and a *bodega* to accommodate his expanding business. As a third-generation *panadero*, he hopes to pass down both his craft and his property to his sons, who are in primary school. Yet Orlando is acutely aware that this future is far from certain. Some of his family members now live in the USA, and he worries his children may follow despite his efforts to instill village pride through participation in community events and excursions in nature. Elena articulates this same tension from a different angle. Her teen daughters attend school in Oaxaca de Juárez, spend time on their phones, and show little interest in learning Zapotec from their grandmother. Yet Elena maintains a courtyard garden full of organic vegetables, harvests with her daughters when she can, and prepares traditional meals over a wood-fired kitchen. She describes these efforts plainly, “I’m just barely getting my daughters involved. Because it’s difficult for a teenager today to truly want to do these things. So we as parents – as people who still have a little more of those lived experiences from our ancestors – we decide to continue, because that part still prevails, right?”²³ Her statement indicates both determination and uncertainty. Like Orlando and Oscar, passing-down knowledge, language, and other practices to the next generation is essential to the community’s survival, but these investments are a wager on a future that cannot be guaranteed.

The forces reshaping Santo Domingo Tomaltepec, including economic migration, urbanization, and climate change, infuse each phase of construction with significant stakes. Building *poco a poco* under these conditions is simultaneously a response to the past – to inheritance and community obligation – and a wager on the future – an act of hope directed toward others whose paths have not yet been determined. Each phase of construction expresses care for relationships and continuities that may or may not be realized: Oscar and Carmen’s house holds space for daughters who may not return; Elena maintains a traditional garden and kitchen for daughters who do not yet want to learn from it; and Orlando’s rooftop restaurant is a vision for sons whose futures remain unwritten. Incrementally built houses like these have no completion condition, which means they remain open to possibility.

²¹ Oscar, interview with author, Santo Domingo Tomaltepec, July 15, 2025. “Si... van a regresar, pero, también ellos tienen otra mentalidad, pues. No lo pensaba estamos platicando que ellos quieren que el tiempo de más atrás porque no se hace como se venía haciendo, porque adoptar cosas que no tienen nada que ver con con nuestras costumbres, nuestra cultura. Y eso este con la deuda es bueno, la deuda, que ellos piensen así también. Pues sí. Son jóvenes que van creciendo.. Y algún día les tocará dar un servicio también, pues pueden este proyectar eso.”

²² Carmen, interview. “Chistoso, ¿verdad?”

²³ Elena, interview. “A mis hijas apenas las estoy metiendo. Eso porque es difícil que a un adolescente, en la actualidad, de Verdad quiera hacer las cosas. Entonces nosotros como papas, pues como personas sabias que todavía tenemos un poquito más de como que esas vivencias de los nuestros antepasados... Pues que dimos seguir porque sigo prevalenciando esa parte, ¿no?”

6. DISCUSSION

The *poco a poco* process of incremental vernacular building in Oaxaca de Juárez's urban periphery is not sufficiently understood through frameworks that have shaped most scholarship on self-built housing. The informal settlements tradition, which ranges from Turner and Ward to contemporary urban studies, most often focuses on how peripheral residents navigate economic and legal constraints, which flattens the motivational complexity of their building decisions. These cases from Oaxaca show that care, aspiration, heritage, and community obligation also drive decision-making as residents navigate layers of dynamic urban conditions. This paper responds to Yiftachel's call for more holistic understandings of urban belonging through attention to resident explanations of incremental decision-making, which is also materially and temporally recorded in their houses.

The research finds that incremental building is simultaneously more strategic, more meaningful, and more uncertain than survival-logic frameworks consider. Economic constraints shape when and how much residents build, but care for family, livelihood, community, and the earth governs what they prioritize within each phase. Attending to care as a motivation reveals construction decisions that existing scholarship has largely overlooked: the sequence in which spaces are completed, the materials chosen for visible façades, and the rooms held open for family members who may not return. Building choices are underpinned by a logic of care that is relational, adaptive, and temporal.

Vernacular architectural scholarship has long insisted that self-built environments deserve serious analytical attention, and that the houses of everyday residents are as worthy of interpretation as monuments and landmarks of official heritage. This paper continues that tradition by attending to the in-process, temporally extended character of incremental building, which is an aspect that scholarship on fixed building types and completed forms has not fully engaged. The *poco a poco* process is both a medium through which residents express belonging and a temporal record through which scholars may explore choices made over time. Each phase of construction leaves a material trace of what residents were caring for at that moment: the golden yellow storefront that announces the family's identity, the *cantera verde* gateway that claims regional belonging, and the unfinished bedroom kept vacant for daughters who may someday return. Interrogated as a sequence rather than a completed object, the incremental house becomes a richer archive of belonging than conventional architectural analysis has recognized.

The findings also demonstrate that identity and territorial claims of belonging are entangled in practice, with implications for how scholars conceptualize placemaking and placekeeping. A single material choice, such as a façade painted the color of *cantera verde*, simultaneously asserts cultural identity and marks territorial presence. Residents do not make one kind of claim at a time, and frameworks that treat identity and territory as

separable registers of belonging miss the layered work that a single building decision performs. Considering placemaking and placekeeping as simultaneous practices, which are made visible through the *poco a poco* process, offers a more holistic account of how residents in the periphery negotiate urban membership.

Together, these findings suggest that the vernacular, self-built houses emerging in the urban periphery are rich sites of meaning-making, worthy of consideration by scholars of vernacular architecture and informal settlements alike. The *poco a poco* process shows belonging as a continuous, care-motivated negotiation, enacted through decades of incremental building and in relation to others and to changing urban conditions. In Santo Domingo Tomaltepec, as in many communities navigating the pressures of urbanization, modernization, migration, and climate change, the unfinished house is not a problem to be solved, but a practice to be understood.

7. CONCLUSION

This paper has argued that houses like Oscar and Carmen's are material and temporal records of belonging, built through care for family, livelihood, community, and the earth. In these houses, residents simultaneously practice placemaking and placekeeping, expressing both aspiration and cultural continuity in their building choices. The incremental houses also represent a form of hope for the future, which is especially uncertain given the pressures of migration, modernization, urbanization, and climate change. The *poco a poco* process reveals that residents continually negotiate their urban belonging, in relation to others, within constraints, and across decades of construction.

In attending to the *poco a poco* process, this paper contributes to a more holistic understanding of how residents in the periphery negotiate urban belonging, extending beyond the legal-territorial focus of informal settlements scholarship and building on vernacular architecture scholarship on dynamic, living traditions of self-built construction. The paper centers the temporal, relational, and care-motivated dimensions of self-built construction. The incremental house, understood as a process rather than a completed object, is a rich archive through which to explore how residents work to negotiate belonging to the city. Attending to how and why residents build in the urban periphery opens new ground for scholarship on vernacular architecture, informal settlements, and urban belonging alike.

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Traditional Dwellings and Settlements

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RESEARCH ON THE MULTI-DIMENSIONAL SPATIAL MODEL AND CLIMATE ADAPTABILITY OF VERNACULAR ARCHITECTURES IN BA YU TRADITIONAL TOWNS

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RESEARCH ON THE MULTI-DIMENSIONAL SPATIAL MODEL AND CLIMATE ADAPTABILITY OF VERNACULAR ARCHITECTURES IN BA YU TRADITIONAL TOWNS



Bayu region specifically refers to the eastern part of the Sichuan Basin and the surrounding areas of Chongqing in southwest China. This paper takes the traditional town residences from the Ming and Qing Dynasties to the Republic of China period in this area as the research object. Centering on the core issue of “how vernacular architectures passively adapt to the hot and humid mountain climate through spatial organization”, it comprehensively employs methods such as field investigation, typological analysis and thermal environment measurement. Systematically analyze its spatial organization model and adaptive construction wisdom in response to hot and humid climate from the three dimensions of horizontal, vertical and composite. Based on the climate adaptability of existing vernacular architecture, this research focuses on the Ba-Yu region and the three-dimensional climate. Through a multi-dimensional systematic deconstruction of the correlation mechanism between their spatial forms and climate performance, it reveals the wisdom of passive ecological construction.

1. INTRODUCTION

With the advancement of the dual carbon goals and the rural revitalization strategy, extracting climate adaptation strategies of contemporary relevance from traditional architecture has become an important issue in the fields of architecture and urban-rural planning. The Bayu region, located in the eastern part of the Sichuan Basin and the surrounding areas of Chongqing, falls within a hot summer and cold winter climate zone, characterized by “humid and rainy conditions with a complex wind environment.” Against this natural climatic backdrop, numerous traditional town settlements, built along mountain contours and waterways, were widely established from the Ming and Qing dynasties through the Republic of China period. Through long-term construction practices, this vernacular architecture gradually developed a climate adaptation system centered on spatial organization, enabling them to maintain relatively comfortable indoor environments without mechanical equipment.¹

However, existing research mostly focuses either on macro-level settlement patterns or micro-level individual buildings, lacking a systematic, multi-dimensional comprehensive analysis of the relationship between spatial organization and climate response—particularly the coupling relationships among the horizontal, vertical, and composite dimensions of residential spaces under hot and humid mountainous climate conditions. In light of this, this study takes the vernacular architecture of Bayu traditional towns as its research object, employing comprehensively methods such as field investigation, typological analysis, and thermal environment measurement. Starting from three spatial dimensions—horizontal, vertical, and composite—it systematically explores the intrinsic correlations between spatial organization patterns and climate adaptation performance, and on this basis, extracts representative passive construction strategies and spatial prototypes, aiming to provide a paradigmatic reference for architectural design practices that maintain regional cultural continuity.²

2. REVIEW OF EXISTING RESEARCH ON BAYU TRADITIONAL VERNACULAR ARCHITECTURE

In recent years, research on the climate adaptability of traditional Bayu settlements and vernacular architecture has formed a multi-level, multi-method cross-disciplinary system. For the specific theme of this paper, relevant achievements can be summarized from four aspects: “settlement morphology – spatial prototype – environmental performance – construction mechanism.”

Regarding the relationship between settlement morphology and microclimate, scholars have primarily focused on the overall spatial structure to explore the regulatory role of settlement form on local climate. Through numerical simulation and quantitative analysis, studies have revealed the coupling relationships between morphological factors such as street block open space ratio, building compactness, and street aspect ratio, and the wind and thermal environments.³ These findings indicate that regular and moderately compact block morphologies facilitate ventilation, heat dissipation, and improved thermal comfort.⁴ Moreover, research from the perspective of “street-house” spatial correlation further points out that streets and buildings form a synergistic mechanism through the continuous transfer of wind and thermal environments, reflecting a holistic and systematic construction logic.⁵

In the area of spatial prototype extraction and green performance research, studies have gradually shifted from morphological description to “prototype-performance” correlation analysis.^{6,7} Through multi-scale deconstruction of typical traditional town cases, scholars have extracted representative spatial prototypes at the settlement, building, and interface levels, and summarized their mechanisms for natural ventilation, shading and heat insulation, and climate buffering.^{8,9}

In research on the generative mechanisms of spatial form and cultural cognition, the introduction of spatial gene theory has provided new perspectives for understanding Bayu settlements.¹⁰ Relevant studies, by identifying landscape pattern genes and land use layout genes,¹¹ have revealed the logic of how traditional settlements conform to the natural environment during site selection and construction,¹² as well as the flexible layout characterized by “disregarding rigid orientation” and the aesthetic tendency of “shaping according to natural forms.”¹³

In studies on natural adaptability and integrated construction experience, some scholars, through large-sample field investigations, have summarized the holistic adaptive mechanisms of Bayu mountainous traditional towns under the synergistic effects of terrain, water systems, and climate.¹⁴ Examples include the spatial organization model of “born from water, flourished by water,” and the construction strategies of building multi-level spatial systems leveraging topographic elevation differences, all demonstrating the comprehensive

utilization and regulation of natural conditions.¹⁵

On this foundation, traditional research on individual building units and technical aspects continues to deepen. This includes field measurements and simulation analyses of ventilation paths, shading structures, and envelope performance in vernacular architecture, as well as investigations into the moisture-proofing and thermal insulation mechanisms of local materials such as wood and stone. Meanwhile, driven by the growing demands for conservation and regeneration, research has gradually introduced digital methods and energy-efficient retrofitting techniques, promoting the transformation of vernacular architecture from “empirical adaptation” to “quantifiable optimization.”¹⁶

Building on existing research, this paper introduces a multi-dimensional analytical perspective of “horizontal – vertical – composite” to integrally deconstruct the spatial organization patterns and climate adaptation mechanisms of vernacular architecture in Bayu traditional towns, aiming to deepen the systematic understanding of their passive ecological wisdom.

3. RESEARCH OBJECT AND METHODOLOGY

3.1. Climatic Characteristics of Chongqing

According to the thermal design zoning for civil buildings, Chongqing falls under the hot-summer and cold-winter climate zone, level 3B. Its climate is characterized by bipolarity and contradiction, featuring high temperatures, high humidity, a high frequency of calm winds, and low sunshine duration. The high-temperature period occurs in July and August, with maximum temperatures exceeding 38°C and a daily average of approximately 27°C. Winters are milder compared to cold regions, with daily average temperatures around 8–10°C, minimum temperatures generally ranging from 3–5°C, and extreme lows reaching as low as 2.8°C. Due to generally low wind speeds and a high frequency of calm winds, the region experiences frequent cloud cover and fog. The monthly sky cloud cover remains around 90% throughout the year, with an annual sunshine duration of about 20% and low total solar radiation, especially in winter (Figure 1).

Unlike flat built environments, mountainous built environments exhibit distinct three-dimensional microclimatic characteristics. Under the combined effects of mountain-valley breezes and land-water breezes, the prevailing wind direction and wind speed differ considerably from macro-meteorological data, displaying diurnal periodic patterns. This study selects several Bayu traditional towns—Linshi Town, Songji Town, Tanghe Town, and the Lu Family Courtyard dwelling as research objects, prioritizing cases that are relatively well-preserved and typologically representative (Figure 2).

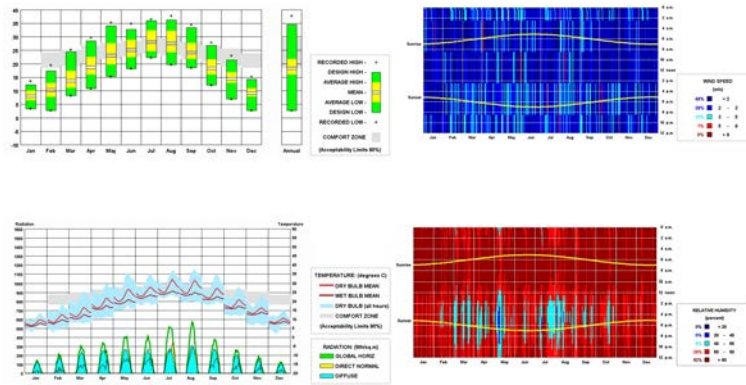


Figure 1: Climate characteristics map of Chongqing. (Source: Drawn by Climate Consultant).



Figure 2: Overview of the traditional town, in the order of Linshi Town, Songji Town, Tanghe Town, Lu Family Courtyard. (Source: Based on satellite images).

3.2. Research Methods

Field Measurement: The Lu Family Courtyard in Linshi Town is selected as the research subject. Its spatial structure remains intact, having undergone only minor structural repairs without large-scale modern renovations. It contains typical spaces such as open halls, courtyards, raised terraces, vertical shafts, and attic levels. Data collection focuses on indoor and outdoor thermal environments. The placement of measurement points follows the principle of combining “horizontal – vertical – key nodes”: (1) horizontally, typical areas such as open halls, raised terraces, courtyards, and transitional spaces are selected; (2) vertically, gradient measurement points are arranged on the ground floor and attic level, and thermal imaging is used to analyze the vertical gradient distribution of temperature; (3) measurement points are also placed at indoor-outdoor buffer space nodes to analyze their temperature variation characteristics.

Typological Analysis: A typological method is employed to systematically classify and summarize the spatial forms of the vernacular architecture. Along the three dimensions (horizontal, vertical, composite), the typical spatial prototypes and organizational patterns are analyzed, and their climate-regulating functions are identified.

4. RESEARCH RESULTS

4.1. Horizontal Dimension Spatial Organization

4.1.1. Narrow and deep plan

Vernacular architecture in Bayu towns generally adopts a “narrow frontage, deep plan” form. On one hand, this responds to the compact land use and narrow alleyways of mountainous terrain; on the other, it facilitates a continuous airflow path. The typical spatial sequence consists of street-facing entrance – open hall – central hall – courtyard (or inner courtyard) – rear chamber, forming a “draft” corridor that runs through the entire depth. Under the prevailing summer wind direction, external airflow enters through doors and windows, driven by wind pressure between the central hall and the courtyard, achieving continuous ventilation. Meanwhile, the elongated space enhances the directional guidance of the wind path, improving ventilation efficiency. In addition, strategically placed side windows and gaps in the facades create auxiliary airflow channels alongside the main ventilation path, promoting indoor ventilation and heat dissipation (Figure 3).

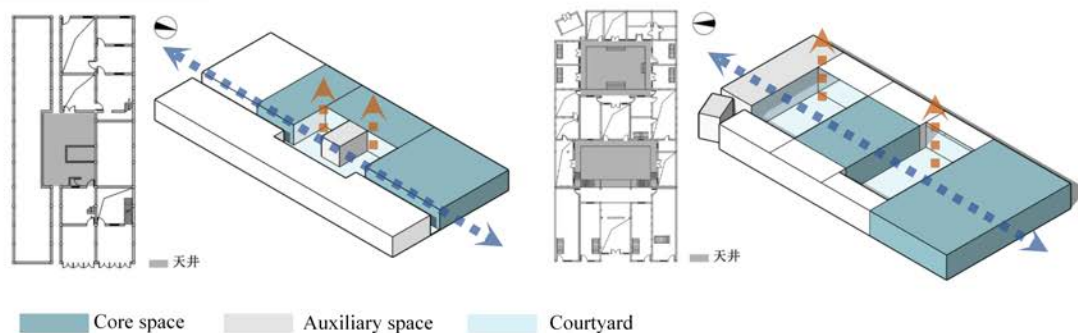


Figure 3: Typical floor plans and schematic diagrams. (Source: Authors).

4.1.2. Hierarchical plan layout

In terms of spatial organization, the core space of the dwelling (e.g., the central hall) is located in the middle or along the main axis, while auxiliary spaces are arranged around the periphery, presenting a gradual transition from public to private and from exterior to interior. This layout not only ensures the security and

privacy of the core space but also allows for flexible use by time and zone. Semi-open spaces such as porches, eaves, and courtyards form multiple climatic buffer zones, creating gradual temperature and humidity transitions between outdoors and indoors. Through multi-layered climate regulation, these buffers effectively enhance the indoor comfort of core functional spaces and maintain their stability (Figure 4).



Figure 4: In the picture, from top to bottom, there are the deep eaves and shading structure, a partially open area on the first floor, scattered auxiliary spaces attached to the main structure, and the patio space. (Source: Authors).

4.2. Vertical Dimension Spatial Organization

4.2.1. Diverse vertical organization

Influenced by the elevation differences of mountainous terrain, settlements are often laid out along contour lines, forming street systems with rich height variations (Figure 5). This arrangement comprehensively captures valley winds and land-and-sea breezes: the main street typically connects a ridge at one end to a riverbank at the other, creating a significant elevation difference. The height variations between and within cold alleys further strengthen the wind-guiding and -directing functions of a three-dimensional wind field.¹⁷

Taking advantage of the flexibility of the column-and-tie construction (*chuandou*) system, vernacular architecture adapts freely to the terrain and exhibits diverse vertical configurations, such as stilted houses (*diaojiaolou*), split-level houses, and houses embedded into the hillside. Elevated or semi-open ground floors can guide low-level airflow into the building, while spatial staggering due to elevation changes helps capture wind resources at different heights, enhancing overall ventilation potential. Meanwhile, elevation differences effectively increase daylighting surfaces, enabling top and high-level lighting, thereby improving the efficiency of natural illumination.¹⁸

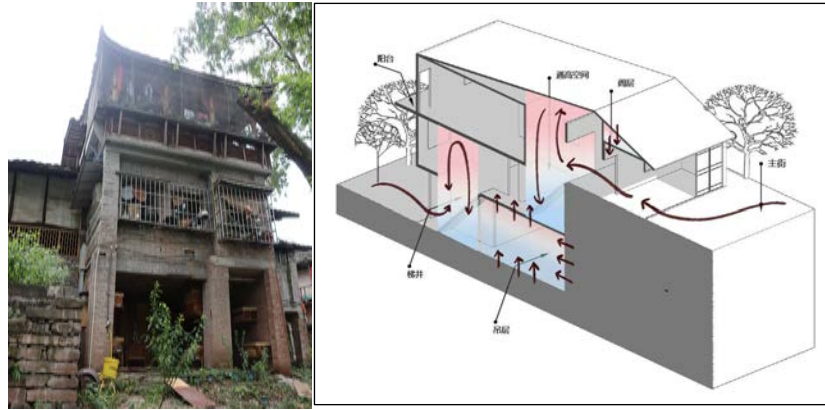


Figure 5: Typical examples of vertical organization and schematic diagram illustrating the climate regulating function. (Source: Authors).

4.2.2. Narrow and tall spatial form

Bayu vernacular architecture frequently adopts “narrow and tall” spatial forms, as seen in high-pitched roofs, courtyards, stairwells, and cold alleys (Figure 6). This form strengthens the stack ventilation effect, enhances indoor heat dissipation and moisture removal, and improves the overall wind-thermal environment. Warm air inside rises and is exhausted through high openings or the roof, while cooler external air is drawn in at lower levels. This facilitates stack ventilation, reinforces thermal stratification, and creates a synergistic wind-thermal effect, effectively addressing ventilation and heat dissipation issues under calm wind conditions.¹⁹

According to the thermal imaging of each vertical space, a significant temperature gradient difference is observed from top to bottom within the space.

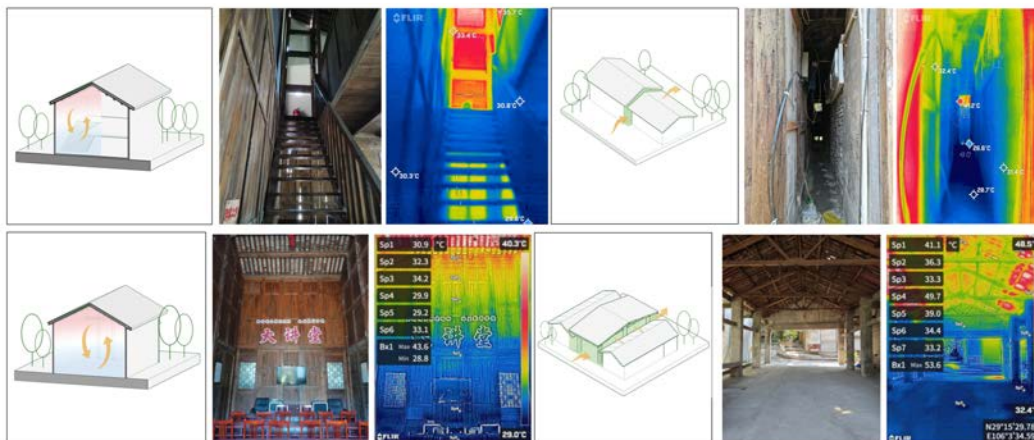


Figure 6: Different narrow and high spatial forms and thermal imaging diagrams, in sequence: stairwell, cold alley, sloping roof high space, open hall. (Source: Authors).

4.2.3. Vertical interface composition

The vertical envelope of Bayu vernacular architecture exhibits a distinct contrast: light and thin above, heavy and thick below. The upper part is covered with small blue clay tiles, which have low thermal resistance, heat up quickly under solar radiation, and reach high surface temperatures, creating an upper hot zone that accelerates upward air movement. The lower part relies on the hillside or ground, which, due to its thermal stability, acts as a natural cold source in summer, further increasing the vertical temperature difference and promoting vertical airflow. Additionally, the vertical distribution and operation of window openings further optimize the indoor thermal and humidity environment, facilitating vertical ventilation, light transmission, and air permeability (Figure 7).

According to the thermal imaging data, the surface temperatures of different materials are all different, and there is a vertical gradient difference from top to bottom.

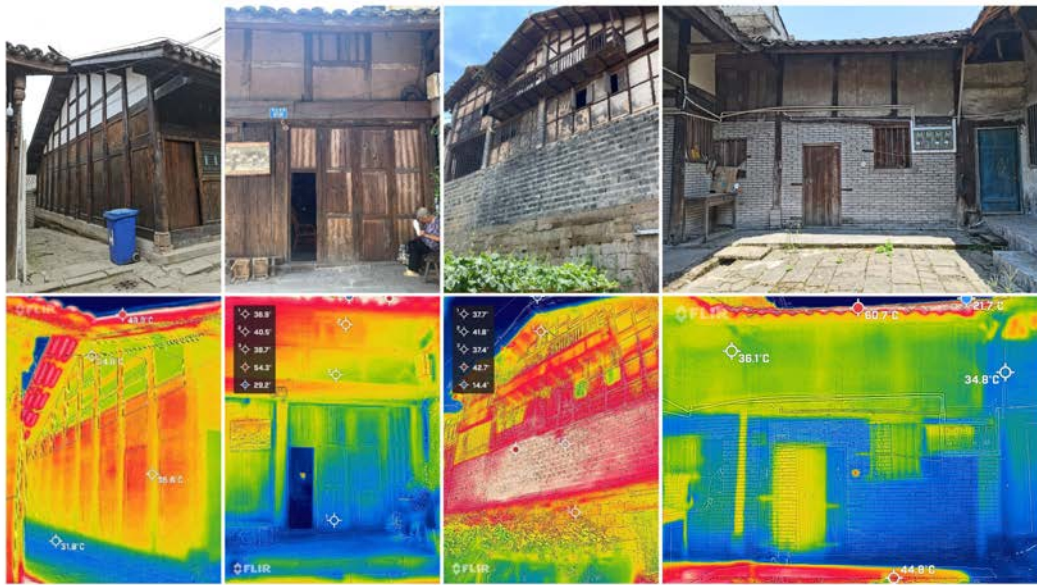


Figure 7: Thermal imaging of the interface between lightweight upper and heavy lower sections. (Source: Author).

4.3. Composite Dimension Spatial Organization

4.3.1. Cross-ventilation path organization

The vernacular architecture of Bayu towns couples horizontal draft paths with vertical stack ventilation channels at different spatial levels, forming a multi-type, multi-level cross-ventilation network. At the individual dwelling level, the main horizontal airflow path runs from the street-facing gate to the rear exit,

while the courtyard and attic form a vertical ventilation shaft; the two intersect at the central hall, creating a “horizontal draft + vertical stack” node. At the neighborhood level, cold alleys and main lanes form primary wind routes, and the street openings and courtyard exits of each dwelling connect into these routes, forming a hierarchical tree-like ventilation network. This composite ventilation system effectively responds to calm or weak wind conditions, improves overall ventilation stability, and avoids air stagnation in local spaces (Figure 8).

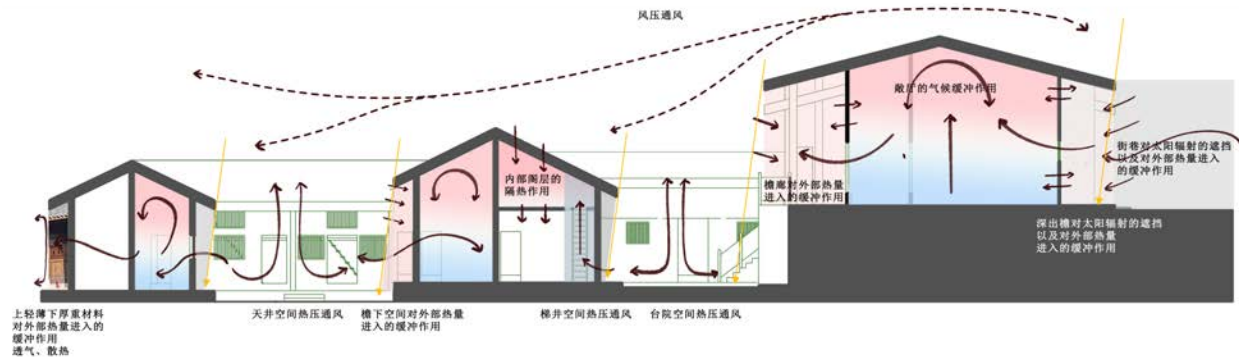


Figure 8: Schematic diagram of climate regulation in the Lu Family Courtyard. (Source: Authors).

4.3.2. Shading and heat protection system

Vernacular architecture incorporates a comprehensive solar shading and heat protection system through multiple measures, including deep overhanging eaves, continuous verandas, lattice windows, and roof pitch design. These features not only reduce direct solar radiation entering the interior but also lower heat accumulation on exterior walls and ground by creating shaded surfaces. Meanwhile, the ventilated roof layer and gaps between roof tiles help dissipate heat, reducing its transmission into the interior and thus lowering the overall building thermal load (Figure 9).

At the settlement scale, compact building layouts create a “mutual shading” effect, where adjacent buildings block direct sunlight for each other, reducing solar exposure on streets and facades. At the individual building scale, eaves, verandas, and staggered volumes form a “self-shading” system, allowing different parts of the building to be effectively shaded at different times of the day. The combination of self-shading and mutual shading not only improves overall shading efficiency but also enhances the microclimate of the neighborhood, demonstrating a high degree of synergy between spatial organization and climate regulation. According to the thermal imaging data, the surface temperatures in the shaded areas are all lower than those of the surfaces in the non-shaded areas.

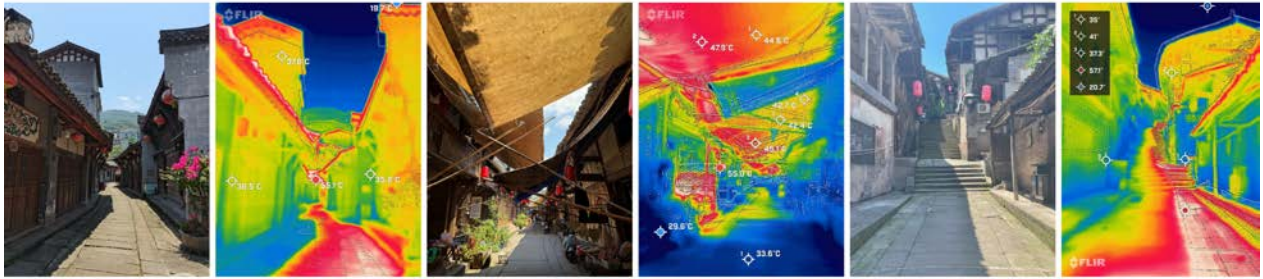


Figure 9: Thermal imaging of self-shading and mutual shading. (Source: Author).

4.4. Typical Dwelling Thermal Environment Measurement Analysis

4.4.1. Measurement point layout

Field measurement selected the typical dwelling Lujia Courtyard in Linshi Town as the main research case. Dwelling A has two floors, faces east–west, adopts a column-and-tie (chuandou) structure, and is generally axially symmetric. Its entrance opens to the street. Influenced by the mountainous terrain, it forms a two-terrace courtyard with a height difference of about 3 m between the front and rear.

The measurement points were: Open Hall A01, Eave Veranda A02, Terrace Courtyard A03, Open Hall A04, Courtyard A05, Open Hall A06, Ground Floor A07 and Attic Floor A08, Ground Floor A09 and Attic Floor A10 (Figure 10). The measurements used temperature/humidity data loggers and an infrared thermal imager. The temperature and humidity data were recorded at 15-minute intervals, during the period from January 2022 to October 2022. The measured parameters included indoor and outdoor temperature and humidity, as well as thermal imaging surface temperatures (Table 1).



Figure 10: Layout of measurement points and aerial view of Lu Family Courtyard. (Source: Authors).

INSTRUMENT NAME	INSTRUMENT MODEL	INSTRUMENT PARAMETERS
Temperature and Humidity Recorder	Tianjianhua Instrument WSZY-1B	Range: Temperature -40 to 100°C; Humidity 0 to 100% RH Resolution: Temperature 0.1°C; Humidity 0.1% RH
Infrared thermal imager	FLIR ONE pro	Range: -20 to 400°C; Thermal sensitivity: 70 mK Accuracy: $\pm 5\%$ of reading; Thermal pixel size: 12 μm

Table 1: Testing instruments and parameters. (Source: Author).

4.4.2. Spatial temperature and humidity analysis

a. Temperature and humidity analysis of each space

In summer (Figure 11), the average temperatures at each measuring point were, in order: A09 (33.7 °C) < A05 (34.6 °C) < A02 (35.1 °C) < A10 (35.5 °C). The diurnal ranges were: A09 (10.7 °C) < A10 (11.7 °C) < A02 (12.0 °C) < A05 (12.7 °C). According to the room temperature data, among the rooms arranged sequentially from the main street inward, the interior spaces exhibited a noticeable thermal lag compared to the spaces near the main street. A02, the eave veranda, reached its maximum temperature between 15:15 and 16:00. The Courtyard A05 had a thermal lag of about 0.5 h relative to A01. The indoor space A09 had a lag of about 1 h relative to A02. The attic space A10 maintained a high temperature for a longer period, staying around 41.9 °C from 16:00 onwards. Influenced by the small blue clay roof tiles and the configuration of the attic floor, A10 heats up quickly and dissipates heat poorly. As the core indoor area, A09, under the influence of thermal buffer spaces such as the eave veranda, Courtyard, and attic, exhibited the smallest temperature fluctuation and the greatest stability.

In winter (Figure 13), the overall temperature was relatively low, with average values around 8–10 °C, and obvious diurnal fluctuations. During the transition seasons (Figure 13), temperatures ranged between 19 °C and 23 °C, with small differences and gentle variations.

Regarding relative humidity, the differences among rooms were large in summer, but small in the transition seasons and winter, where the variations were very close. In summer, A02 (eave veranda) reached its highest humidity between 5:00 and 7:00. The indoor space A09 had a lag of about 1 h relative to A02, and the average humidity difference was 5.6 %. In the transition seasons, the average humidity difference was 1.7 %; in winter, it was 4.2 %.

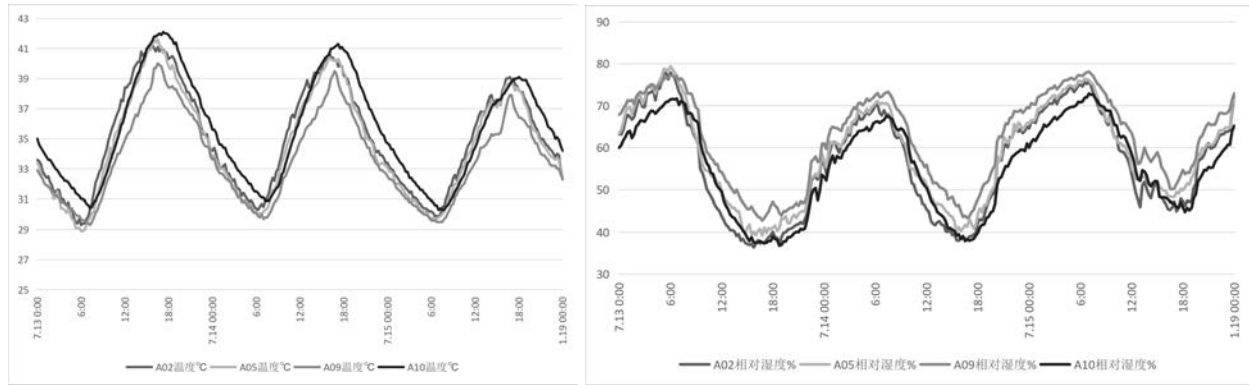


Figure 11: Temperature and humidity in various spaces during summer. (Source: Authors).

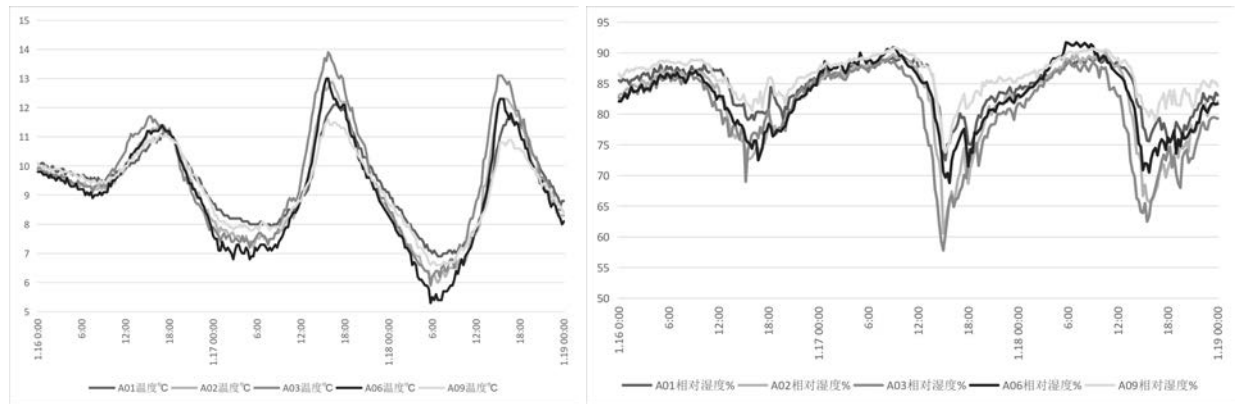


Figure 12: Temperature and humidity in various spaces during winter. (Authors).

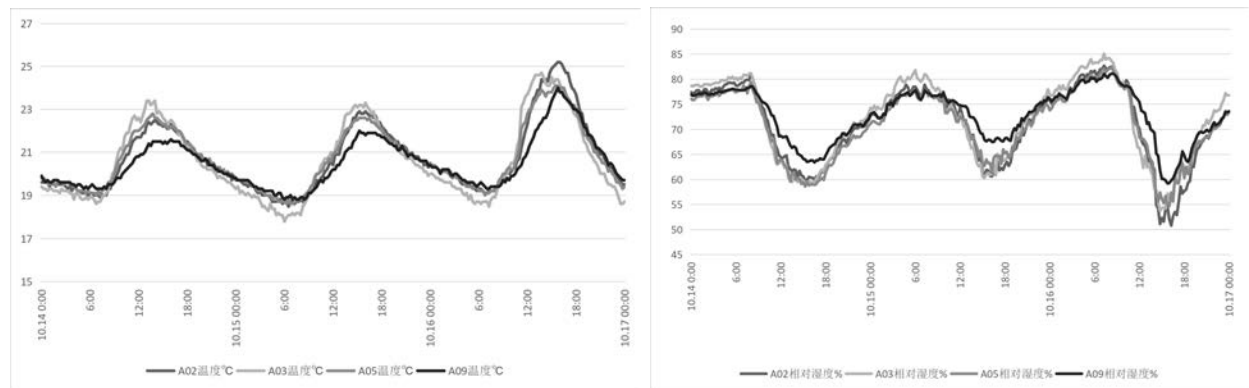


Figure 13: Temperature and humidity in various spaces during the transition season. (Source: Authors).

b. Comparison between ground floor and attic level

As shown in the figure (Figure 14), the attic temperature is higher than the ground-floor space in all seasons. In summer, the attic room A08 reaches its maximum temperature between 16:30 and 19:30, while the ground-floor room A07 reaches its maximum between 17:30 and 20:00. Influenced by the attic buffer space, the high-temperature period on the ground floor is delayed by about 1 hour relative to the attic, showing a clear thermal lag. Although the ground-floor room A09 and the attic space A10 both reach their maximum temperatures between 16:00 and 17:00, the temperature in A10 is 41.8 °C, and that in A09 is 39.7 °C, indicating that under the influence of the buffer spaces, the ground-floor temperature is reduced by 2.1 °C. Meanwhile, the average temperature of all attic spaces is about 1.8 °C higher than the average temperature of the ground-floor spaces.

In terms of relative humidity (Figure 15), the seasonal average relative humidity values are, in order: A08 (54.9 %) < A10 (55.6 %) < A07 (60.4 %) < A09 (62.1 %). In summer, the average humidity difference between the attic and the ground floor is 5.5 %–6.5 %, while the difference is small in the transition seasons. The relative humidity fluctuation values in summer are ranked as: A10 (34.9%) > A09 (34.4%) > A08 (31.8%) > A07 (27.6%), with small differences in the transition seasons.

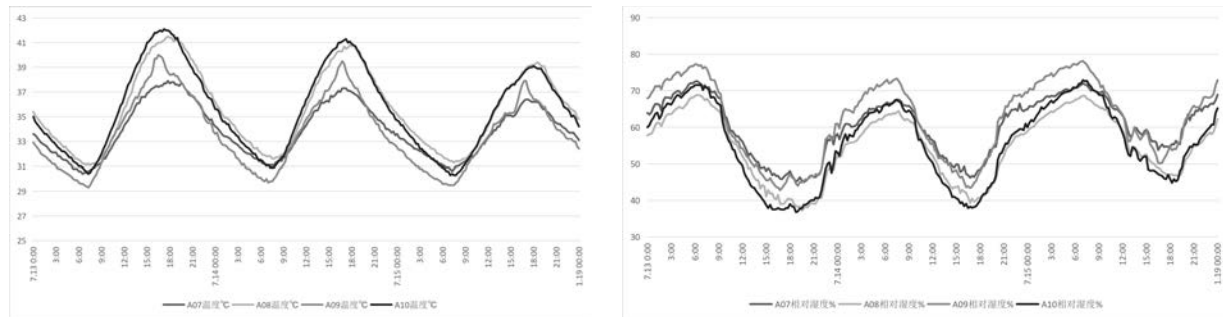


Figure 14: Temperature and humidity in ground floor and attic spaces during summer. (Source: Authors).

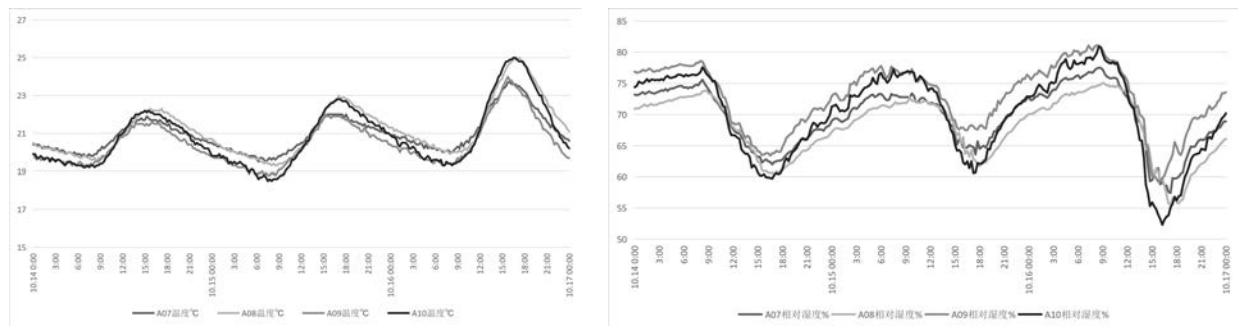


Figure 15: Temperature and humidity in ground floor and attic spaces during the transition season. (Source: Authors).

c. Composite buffer spaces over a continuous period

To comprehensively evaluate the regulatory effect of horizontal and vertical buffer spaces on the thermal environment of indoor living spaces, a continuous three-day period during the high-temperature season (August 16–18, 2022) was analyzed. The five hottest hours in each time period were selected for comparison. The analysis results show that, compared to August 16, the average temperature during the high-temperature period (11:00–16:00) outdoors (A05) increased by 1.04°C on August 17 and by 1.35°C on August 18. For the vertical buffer space (attic A08) during its high-temperature period (14:00–19:00), the temperature increased by 0.71°C on August 17 and by 0.87°C on August 18. Among the horizontal buffer spaces, during the high-temperature period (14:00–19:00) of the eaves veranda (A02), the temperature increased by 0.77°C on August 17 and by 1.09°C on August 18; for the courtyard (A03) during its high-temperature period (9:00–14:00), it increased by 1.82°C on August 17 and by 0.22°C on August 18. For the ground floor living space (A07) during its high-temperature period (14:00–19:00), the temperature increased by 0.78°C on August 17 and by 0.41°C on August 18.

It can be concluded that for every 1°C increase in outdoor temperature, the vertical buffer space warms up by approximately $0.6\text{--}0.7^{\circ}\text{C}$, the eaves veranda by approximately $0.4\text{--}0.5^{\circ}\text{C}$, the courtyard by approximately $0.8\text{--}0.9^{\circ}\text{C}$, and the ground floor living space by approximately $0.4\text{--}0.5^{\circ}\text{C}$, which is about half of the warming rate of the horizontal and vertical buffer spaces. Therefore, under the coordinated organization of the composite buffer spaces, approximately 70% of the cooling effect can be achieved when the outdoor climate passes through the buffer spaces and reaches the indoor living spaces (Figure 16).

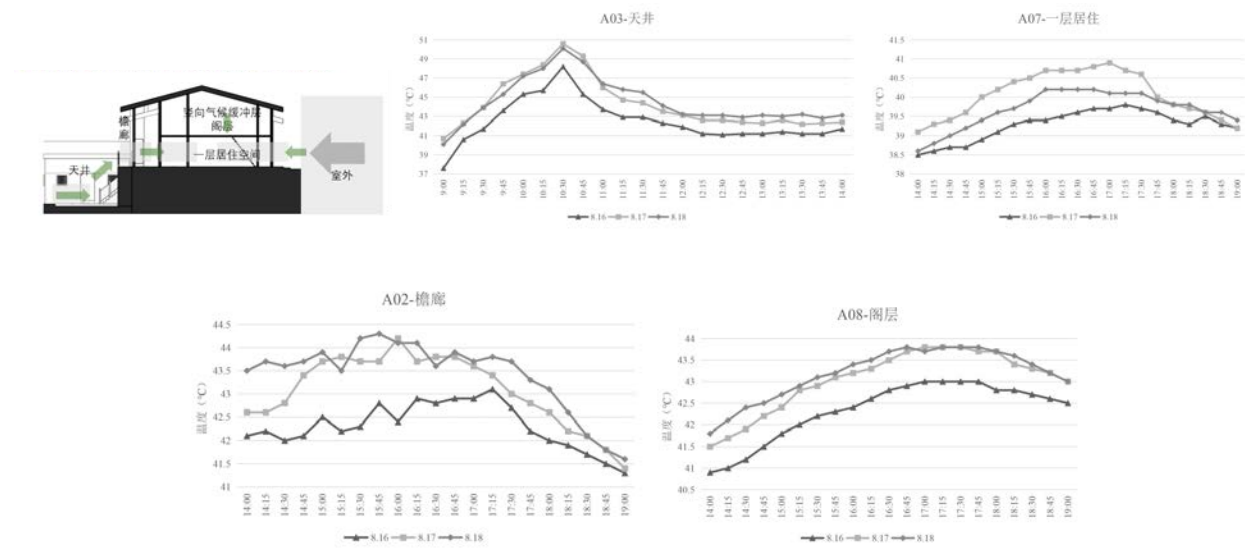


Figure 16: Temperature variations during peak heat periods in each space. (Source: Authors).

5. CONCLUSION

On the horizontal dimension, the hierarchical plan layout effectively ensures the thermal stability of the core space. Bayu mountain vernacular architecture adopts a deep, narrow plan form to create a stable core thermal and humidity environment. Measured data show that from the street side inward, temperatures decrease gradually and fluctuations become gentler. Accordingly, the traditional layout places the core space in the middle, with auxiliary functional spaces at the front and rear serving as climatic buffer layers, effectively enhancing the thermal and humidity stability and comfort of the core area.

On the vertical dimension, the vertical spatial organization creates a climatic gradient effect, enabling dynamic thermal regulation. The high space under the pitched roof, together with the attic floor, forms an effective “climatic buffer layer”. Measured data show a significant vertical temperature gradient distribution, and through the “stack ventilation” effect, accumulated hot air is continuously expelled from the building.

On the composite dimension, multiple levels of thermal buffer spaces work together significantly. Under the coordinated organization of horizontal and vertical buffer spaces, the outdoor climate can be attenuated by about 70 % by the time it reaches the indoor space via the buffer spaces.

In summary, the spatial patterns and construction wisdom embodied in Bayu traditional vernacular architecture reflect a passive green intelligence that is based on regional conditions, centered on spatial patterns, and oriented toward climate regulation. This provides suitable, localized green design references and paradigms for sustainable design of contemporary mountain buildings and the improvement of the human settlement environment in hot and humid regions.

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MATERIAL TRADITIONS, CRAFT, AND INDIGENOUS KNOWLEDGE SYSTEMS

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