Studying the landscapes of north-western Rajasthan through its resource repository.

Abstract

The Earth's landscapes have evolved continuously, with variations often discernible within meters from a point. The most tangible result is the plethora of possibilities each landscape presents that directly affects how civilisations survive and thrive. Since antiquity, buildings and allied constructs in north-wester Rajasthan, India have been a product of the very landscape they are built on, primarily dependent on the resource it yields and the varied skills it supports. This repository of knowledge and understanding is influenced by cultural, political and trade exchanges, similarities in the climatic conditions, and of course, the available skillset. Effective dialogue is critical to help comprehend the learnings from our past to help us work within the current sphere of an ever-evolving, fast-moving world while still being rooted in a context. What often gets lost is the ability to repair, maintain and rebuild, if needed.

Keywords: Rajasthan, material study, traditional, built environment, geographical landscapes

"*Houses reflect the nature of a region since their character is related to the environment and to the cultural heritage of the people who build them. Houses reflect the nature of the rock material or the vegetation that forms the basis for their construction.*"

(Samuel Newton, 1970)

Introduction

A region of varying ecologies and geologies, where the land is a mix of a semi-arid and desert ecology; delineated on the east by one of the oldest mountain formations on Earth – the linear tract of the Aravalli and a desert rolling into the west, but the Indian state delineates at the borders between India and Pakistan. Rajasthan has 50 per cent of its area under the desert ecological and geographical zone, where the annual winds bring with them heaps of sand from across the border to this land and further onto the Ganges plains. The absence of perennial rivers drains the plains. It is a region where rainfall is measured using fingers as a scale. A land spread across an area of over three lakh square kilometres, bordered by Pakistan in the west, Punjab and Haryana in the north-north-east, Uttar Pradesh, Madhya Pradesh in the east, and flanked by Gujarat in the south, separating it from the Arabian Sea. The study area is the portion to the north-west of the Aravalli is a mix of sandy arid plains and semi-arid transitional plains; the sandy, ill-watered desert to the far west becomes more habitable and fertile as one move towards the east.

Figure 1 A cross-section through the landscapes of Rajasthan as one move from the western sandy arid plains towards the northeastern hills

a. Tanot, Rajasthan
a. Narsinghani, Rajasthan
b. Toonga, Rajasthan
c. Amer, Rajasthan

With the air's dryness and the rising waves of sand, scarce rainfall, with extreme heat and temperatures, the people in the region have adapted to the conditions and evolved to survive and thrive. The communities' lifestyle is in sync with the climatic variations and the local ecological changes. The arid and semi-arid regions of the state are not arable enough to support an economy based on agricultural produce, thus relying primarily on pastoral sources, seasonal agriculture and at-times by trade. Facilitated by the state's strategic location, several trade routes have traversed through the region over the centuries traversing west to east and north to south, connecting towns across the continents. Buildings here are designed to sustain and serve as a shelter from unwanted guests in the form of humans or climate and made using local materials and indigenous technologies of the land and immediate or nearby context; a mélange of possibilities based on its geology and ecology.

Figure 2 Camels were often extensively used in the western regions of Rajasthan, India

The research aims to map and understand the physical manifestation of the limited palette of resources available through northwestern Rajasthan.

Settlement and their buildings

Traditionally, the towns and villages housed a series of activities that were a part of its residence's daily functioning along with the houses of the ruling families. To maintain law and order and administrative works within the towns, several administrative buildings, like the courthouses, public assembly spaces and administrative wings in the *garhs*[1], palaces and forts. The residential buildings in the towns housed the traders, people working in administration, law enforcement and palace staff and the commoners. A public and private system provided utilities and services through multiple sources. Water sources depended on the geology and hydrogeology of the region and the availability of natural catchment areas, which eventually developed as lakes, *tankas*[2], *baoris*[3], wells. Interspersed within towns and along the highways are religious complexes and *caravan serais* that provide travelers a reliable water source. Markets sitting along the arterial roads in towns facilitated trade and commerce through a series of shops and commercial establishments. The buildings' location and planning are based on the principles responding to climate, construction materials, and skills available within the region. Principles that have worked and lasted for centuries.

Physical landscapes

The mountainous tracts end near Jodhpur, rolling into the sandy desert. Into the "*marusthaal*" [4], a term used for the region of the Thar in India; a large portion was non-taxed back in time, and even today ", *Jaha phog*[5] *hai waha bhog nahi ha*i" *(translates into, "a land where the phog grass grows that parcel cannot be taxed")*. Despite the arid traits, the land support numerous villages and towns. The soil structure in Rajasthan regions is more diversified than the prevalent climates in the study's different parts. The broader classifications could be under arable, sandy and rocky. The regions of Rajasthan around Jaisalmer is sandy and rocky, and Bikaner is a mix of rocky and sandy with tracts of arable and around Jodhpur, regions of Shekhawati and

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[1] *Garh - a garh is a combination of the palatial (residential) and fortified buildings (defense) of the royalty in the rajput royalty.*

[2] *Tanka - A water structure in the state built to collect the rainwater falling in the surroundings/catchment areas or just an underground storage tank. The base and walls are masonry walls lined in lime to prevent loss of water due to storage and are often seen with a cover to prevent water loss as vapor.*

[3] *Baori - A water structure including a long flight of steps several storeys below the ground level leading to the water in the well shaft below. The shaft could be used to directly haul up water, although the steps provide direct access to the same. Along with the well, spaces are designed around to provide a place to rest.*

[4] *Marusthaal - A name given to the Thar desert in Rajasthan.*

[5] *Phog (Calligonum polygonides) - A plant with an extensive root system, grows on sand dunes. Its leaves serve as fodder for sheep, while its flowers are eaten by the locals. It is used as firewood and in building as a part of the roofing.*

Jaipur one sees a mix of arable, sandy and rocky. The hills are an elevated mass providing large reserves of building stone. The isolated hills and part ranges are an elevated guided mass for settlements and building type in the region. A mix of igneous, sedimentary and metamorphic rocks of different ages and types interspersed across the region's hills. Marble is found in the region of Nagaur, Alwar, Jaipur and Jaisalmer; granite in Ajmer, Alwar, Barmer, Jaipur, Jaisalmer, Jalor, Jhunjhunu, Jodhpur, Nagaur, Sawai Madhopur, Sikar and Tonk region; sandstones in found in the regions of Jaisalmer, Jodhpur, Bikaner, Nagaur, Pohkran, Tonk, Churu and limestone in Jaisalmer, Nagaur, Jodhpur, Jhunjhunu. (India, 2011).

Figure 3 A map of the erstwhile kingdoms of Rajputana (from the 1900s) and its geography. Rajasthan, India

Physical landscapes and materiality

With the paucity of building stone and resources in some northwestern Rajasthan regions, the buildings in antiquity constructed in timber frames covered in mud, sun-dried mud bricks, and *daab*[6] for the construction of walls. Mud has been an integral part of the build in the region due to the ease of availability and the large repositories of knowledge systems that have existed for the millenniums in the region; an example is mud bricks and plasters in the remains excavated at Kalibangan. (B. B. Lal, 2003). The earth for the building was generally collected from the beds of water collecting depressions around the towns and villages. Out of the 515 villages in the Jaisalmer district, 294 villages had a large-sized lake, and the remaining have smaller water bodies in the form of lakes, wells and *tankas* (Mishra, 1995), acting as reservoirs and a source of the earth to be used in the buildings.

In its physical states, coherent by nature, the earth is used in multiple ways through the buildings as plastic and rigid. Plasters, mortars, floor fills and finishes are the bound and layered form of earth used in a plastic state with plant and mineral-based additives to give it strength and workability. Earth's use in a rigid form is in adobe brick, cob walls, *daab* walls, and kiln baked bricks, where pressure or heat helps change the adobe brick properties. Compression of earth allows it to get its desired strength by consolidating it and making it denser. (Wright, 2005)

The household members made the sun-dried adobe bricks along the lakes' banks as per need especially during the drier seasons of the year. The bricks were of varying proportions and thicknesses as one moved through the east-west trail through the state, primarily due to the earth's quality, properties and additives available. The walls set in a mud mortar and are often plastered with a mix of mud and additives (cow dung, cow urine and plant-based fibres from the last season crops and locally available grasses). Renders of clay-rich soil provided a waterproofing layer on the flat terraces of houses and *havelis*[7] in Jaisalmer, similar to the waterproofing seen in the houses in Ladakh[8]. To increase the strength and durability the terrace finished were beaten with branches to remove excess water over a period of time*(in Jaisalmer the branches from kair shrub is used)*. The forts in places where quality limestone was scarce, the stone masonry wall was set in mud mortar like the bastions and fortified walls of towns like Dudu and Bharatpur near Jaipur. Several houses in the Jaisalmer district or near the ones near quarries use stone masonry wall walls in an earth-based mortar and plaster.

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[6] *Daab - Daab is a regional variant of cob wall construction locally practiced. The difference in daab construction unlike the traditional cob construction a heap of the mix is taken and pressed down as a continuous layer. A rise of a foot is given to each layer and immediate layers are interlaced with broken branches that as a reinforcement to enhance the structural capabilities of the wall.*

[7] *Haveli - A courtyard mansion with a degree of refinement in planning, aesthetics and structural and material understanding. The havelis were generally dwellings for the upper classes in the region.*

[8] *Markalah is a mud found in the western Himalayas used for construction and decorative purposes. It is known for its high clay content, thus is used as a waterproofing layer on terraces of the houses in Ladakh.*

Seri mitti, safed murud, pandu are local names of various mud types found in the region, with different compositions and similar attributes of a light almost white colour finish in the external render used on buildings.

Multiple colours and finishes make up the palette of renders depending on the location and soil types available; *seri mitti* as a whitewash in Jaisalmer (Rajputana Gazetteers, 1909). The red clay found near Bikaner is the base to plaster the walls to emulate the red sandstone commonly used in the region's facades and provide a water-resistant layer and white clay found in the region for the whitewashing of the walls. Coarse *murud* is used in the eastern part of the region to provide a surface render that is more resistant to the annual rainfall in the regions, especially around Jaipur. A lighter off-white render in the region of Jaipur was using *safed murud* or *pandu* found in the region. The mud-based renders on the walls and waterproofing layer on the terraces need regular maintenance especially before and after the monsoon season with an appropriate slope to allow the water to pass rather than stagnate.

Figure 4 Making and use of mud in the various types of buildings in the region

a. *Adobe bricks drying on the banks of a lake at Ajmeri, Rajasthan*
b. *Mud finished floor of a gate in Jaisalmer, Rajasthan*
c. *A house-made up of adobe bricks walls in Netsi, Rajasthan*

The mud forts in the region predate the discovery of the quarries in some of the areas. Many forts in the former state of Bikaner, like the Pugal Fort *(the lower section of the 1200-year-old fort),* use thin mud bricks in tapering walls and are set using mud mortar. The treacherous terrain and sea of sand provided a hostile environment for the enemy and a natural terrain as a defence mechanism for the region's military establishments. Several forts in present-day Pakistan and India have a portion of their older structure or entirety in mud.

A limited palette of resilient trees and shrubs have survived in the region for centuries as part of the local ecology of the region; often used as food, fodder or building material for a shelter. Shrubs like *aak* (*Calotropis gigantea*), *phog* (*Calligonum polygonides*), *kareel/kair* (*Capparis decidua*), *paani* (*Vachellia nilotica*). The branches of the *aak* plant make up the wattle's lattice, sandwiching between the two layers of the mud daub walls. Shrubs and branches constitute the vertical and lateral supports along the thatched roof of grasses like *paani* or remains of the last season's crops like bajra or wheat that were woven together in a predefined pattern and maintained regularly with a frame work made in timber logs, especially *kair* branches in the region of Jaisalmer. The husk from the crops like *bajra, wheat, jai* and *jowar* is part of the fibrous plaster and sun-dried bricks. Fibre is added to the mix to be left overnight, making the bricks stronger, ease to work with and less absorbent (Facey, 2015).

The timber from *khejri* (*Prosopis cineraria*), *rohida* (*Tecomella undulata*) or known as the teak of the desert, *babul* (*Acacia leucoploea*), *neem* (*Azadirachta indica*), *sheesham* (*Dalbergia sissoo*) logs make up members to support and span roofs and transfer the vertical loads through columns. The branches and smaller sections of the timber provide timber for boarding and joist in the flat mud roofs. The use of timber for the facade ornamentation using a local variant of *babul* is seen in Nagaur. The use of hardwood like *rohida* was to carve decorative elements in the structural framework *(like beams and lintels)* in Fatehpur and non-structural members *(like door and window frames and shutters)*, especially in the havelis in the towns of Churu, Ramgarh, Mandawa and Bissau. The cutting and harvesting of trees for timber kept in mind the season and climatic conditions to reduce the possibility of attacks by the locally found pest and increase longevity.

Figure 5 Shrubs and trees of North-Western Rajasthan

a. aak (Calotropis gigantea)
b. kareel/kair (Capparis decidua)
c. babul (Acacia leucoploea)
d. sheesham (Dalbergia sissoo)

Several indigenous techniques are employed to prevent termite[9] attacks on the woodwork using plant, animal and rock-based additives. The use of cow urine, processed sap of *aak*, *kheemph* (*Leptadenia pyrotechnica*), *neem* tree in Jaisalmer; regions around Jaipur saw the use of ash from a wood-based fire stove (the use of ash seen in the mortar remains excavated at Kalibangan. (B. B. Lal, 2003)), processed sap or cakes of the neem tree and remains of the *bajra* plant was is to provide termite resistance. Along with the insect and termite repellent properties, plant additives are added or rubbed on a surface using a broom for their medicinal and healing properties.

[9] *A number of species of termite or locally called udai or dimak is found in Rajasthan especially in the desert region. Termites are known to infest the living and the dead crops, grasses, shrubs and trees of the area. A number of indigenous methods have been used over the years to reduce the damage caused by them to buildings, crops and fauna. (Parihar, 1981)*



Figure 6 Timber as a structural and ornamental member

a. *Pani grass in the roofing and a timber column is used in a pavilion outside the house in Kansel,*
b. *Intricately carved lintel and door frame of at the entrance in a haveli in Mandawa, Rajasthan*
c. *Use of timber sections of various sizes to support a patti floor in the garh at Bichoon, Rajasthan*



Figure 7 Timber as a structural and ornamental member

a. *A wooden beam supported on stone brackets as part of the fort complex in Jaisalmer, Rajasthan*
b. *A wooden lintel supporting the roof and a cantilevered sunshade in Nareda, Rajasthan*
c. *A wooden beam supported on wooden brackets in a haveli in Mandawa, Rajasthan*

The isolated mountain tops were active quarries, until recent years, with a possibility to yield a substantial amount of stone for building. Other reserves of stone, a couple of feet below the surface, are blocks rich in lime content *(known as Jhanjhar Bhatta*[10] *locally or kunkur)*, used as irregular blocks or roughly shaped blocks similar to those seen in ashlar masonry. A region with several towns like Bissa, Churu, Ramgarh, and Mandawa,

[10] *Jhanjar or dhadhala bhatta or kunkur - is a form of calcrete; which is mostly a calcium carbonate accumulation whose formations involves dissolution, transport and accumulation at a depth in the soil profile of the carbonate already present in a thickness of sediments or that brought in solution by runoff water or as sediment/dust from surrounding landscapes. These are typical formations of a semi-arid climate, where rainfall during a part of the year is sufficient enough to cause mobilization of carbonate as percolating soil solutions to be followed by a period of dryness for dissolved material to precipitate at a depth (R. P. Dhir, 2018) (Goudie, 1983) It was burnt in kilns to produce lime in the belts around south and southeastern region of Jaipur.*

mainly in the Jhunjunu and Sikar district of the Shekhawati region and some extensively around Jaipur, as the core material in the walls along with the baked bricks. Erosion and disintegration of the blocks is seen over a period of time if walls made with *jhanjhar bhatta* are left exposed or un-plastered due to wear and tear, physical and chemical composition of the blocks.

Figure 8 Stone as a structural and ornamental member

a. *Dry stone masonry stepwell in Mauzmabad, Rajasthan*
b. *Jhanjhara bhatta walls in a garh in Madhorajpura, Rajasthan*
c. *Ornately carved chhatri at Amar Sagar in Jaisalmer, Rajasthan*
d. *Sculpted pattern of a column in haveli at Mandawa, Rajasthan*

In the towns and villages where stone is abounding and is soft enough to be sculpted, one sees forms hand-shaped by the mason's hand. In places where the stone was not available, boulders moved on bullock or camel carts from the location of availability to the location of need. The fort at Bikaner built by Rao Rai Singhji was built in 1588-1593 using stone imported from Jaisalmer, and the fort at Islamgarh, Pakistan, was built around 1665 using the stone imported from Jaisalmer, and bricks used were locally sourced (Iqbal, 2002). The use of stone in places of availability for structural or ornamentation depended on the type, quality, and location used.

The use of long and sturdy timber logs is scarce, and the use of stone is extensive in the forts and palaces, public buildings, houses of the mercantile community, and the region's commoners house. In the commons' houses, the use of stone masonry, both random and dressed, set and plastered in mud or lime mortar, is extensively seen. The use of dressed stone masonry with a mud lined flat roof is extensively seen in the ruins of Khabha and Kuldhara; stone *pattis*[11] or timber sections held up the roof, similar to the construction seen in the buildings in Jaisalmer. The construction of buildings in Jaisalmer uses the locally sourced yellow sandstone through a jigsaw puzzle method, laying the blocks according to weight or using a stone key/iron clamp with limited or without using mud-based mortar, making it easier to replace and repair. The softness in the sandstone at Jaisalmer is often compared to timber. The *havelis* in Bikaner and Jodhpur use intricately carved red sandstone panels with stone masonry walls lined in lime mortar. Some *havelis* in Jodhpur had walls constructed in inches thick stone slabs devoid of any mortar with a cavity, using the rat-trap bond principles

[11] *Patti - Cut stone slabs of 12-15ft length and 3 ft wide approx. and a couple of inches thick used as slabs for flat roofs in the region.*

similar to the *havelis* seen in Nimbahera[12], Rajasthan. Buildings in Khatu have used sandstone for making doors, stone frames, perforated windows and *jaalis*[13] Stone *pattis* used in roofing quarried from the sandstone quarries at Jodhpur and Toda Raisingh are used in buildings. An extensive used of random rubble and undressed masonry is seen in regions around Jaipur and Shekhawati.

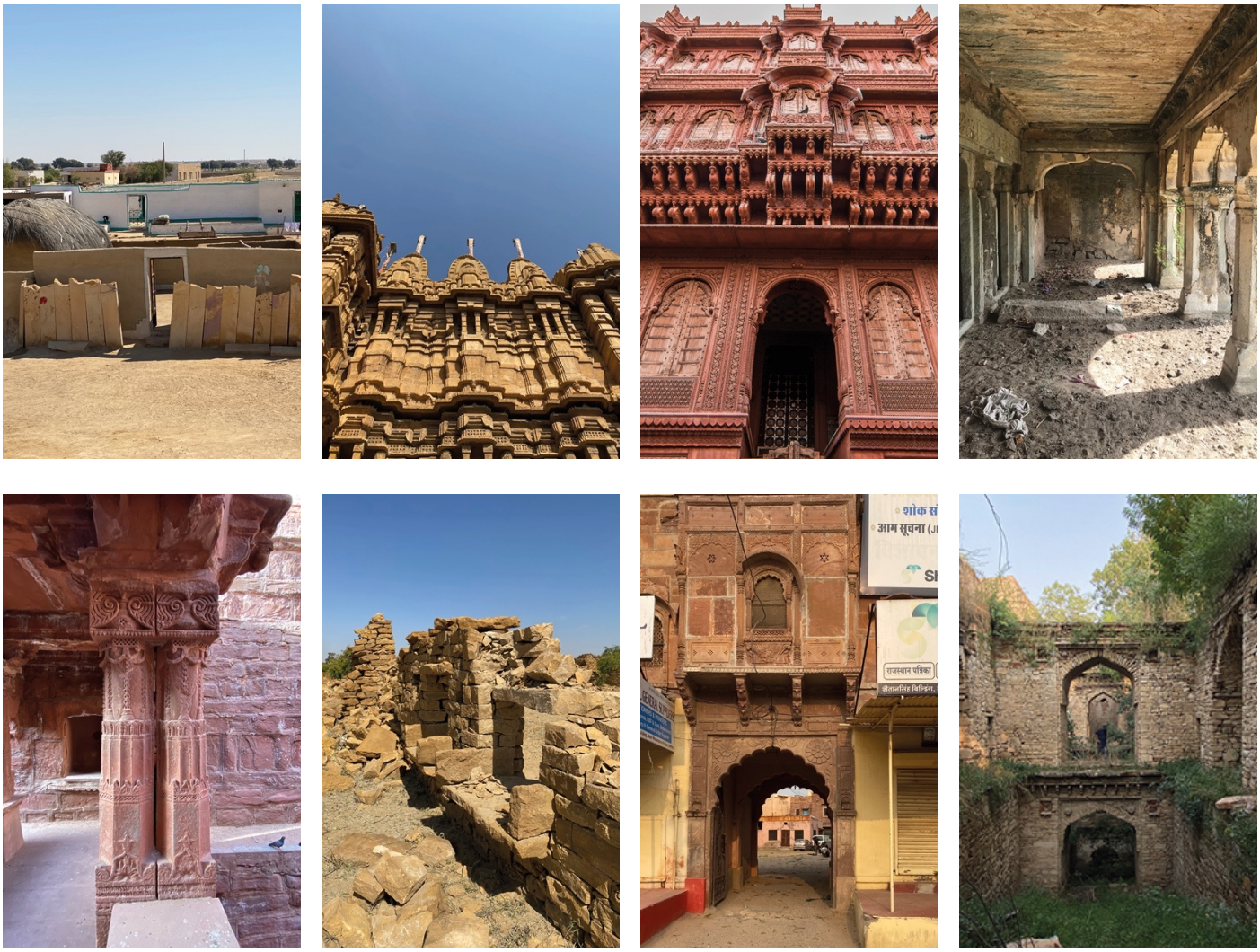

Figure 9 The use of building stone changes across landscapes from being ornamental or structural; either using a part to complete a whole or a whole plays a role in a part.

a. *Pattis used as a compound wall in a house at Netsi, Rajasthan*
b. *Intricate relief work in the Shikhar13 of Shri Chandrapur Mandir in the Jaisalmer fort, Rajasthan*
c. *Intricate relief work in the facade of a haveli at Bikaner, Rajasthan*
d. *The use of cut stone arches and pattis in the garh at Kothawada, Rajasthan*
e. *Monolith columns of a Tapi Baori in Jodhpur, Rajasthan*
f. *Walls of dressed sandstone blocks of houses in Kuldhara, Rajasthan*

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[12] *Nimbahera is a town part of the former princely state of Tonk. It is known for its splittable limestone that has extensively been used in the havelis constructed in this town. 2-3 inches thick limestone slabs are arranged vertically to construct a double layered wall with a cavity in the middle.*

[13] *Jaali - A perforated stone or lattice screen extensively used in the zenana portion of the garh or haveli. A device used to see the happenings of the outside world restricting the view of the inside.*

g. *Jodhpur stone slabs used in the wall of a pol in Jodhpur, Rajasthan*
h. *Random rubble stone masonry using smaller blocks of stone in a Baori at Panchota, Rajasthan*

In places distant from the hills and had limited access to natural reservoirs of good quality building stone, baked bricks' use is extensive. Bhatner – Hanumangarh forts are built in the *lakhori*[14] bricks set in mud mortar. The use of baked brick lined with lime mortar in the Havelis in Bikaner, Choru near Jaipur. The use of bricks of varying sizes in the region, the thin *lakhori* bricks in Bhatner to the baked brick remains from the excavated settlement at Naliasar to the broader than standard dimensions of square bricks at the *garh* in Chittora. Handmade brick kilns are interspersed in the region to date; however, regularising the sizes as per the commercial requirements.

Figure 10 Various form, size and types of mud bricks used for walls and arches around Jaipur district, Rajasthan

a. *Front faced with irregular back bricks in the excavated remains at Naliasar, Rajasthan*
b. *Bricks wider than the hand seen in the wall of a Haveli in Phagi, Rajasthan*
c. *Thinner bricks of a masonry wall in Mauzmabad, Rajasthan*

Lime was extensively used for construction and ornamentation in the region in the form of mortar, plaster, and stucco works on the walls and ceilings. The use of lime finish in places where good quality cladding stone or ornamental relief work is extensive due to the geological and property variation of the stones locally available. In the Shekhawati and the region around Jaipur, *jhanjhar bhatta*, a core building material in other regions, was a good coarse lime source after burning it in a kiln. In Kirod and Bhasawa, near Nawalgarh, Jhunjhunu district, lime was obtained from a blue-grey marble burning; remains of dust and chips from the quarries in Makrana were burnt in a kiln to obtain lime. Gotan and Sojat in Nagaur have been important sources of good quality lime for building and are used to date. In Jaisalmer, the use of quarried limestone or shell lime *(from the remains of the sea that existed long ago)* to obtain lime for building construction in the region. In the region around Jaisalmer like Mohangarh the lime was fired by people using cow and cattle dung cakes locally for 12-14 hours. A form of sweet lime at Sardarshar near Bikaner obtained by burning a peculiar variety of clay excavated from the sand-hills and, due to its early setting time, it is primarily utilised for building purposes. (Rajputana Gazetteers, 1909). Some functional and largely abandoned or shut down lime kilns spread across the towns are the signs of the natural deposit of limestone regions. However, there is some locally identified source of good lime used for construction in the other regions.

[14] *Lakhori bricks - are flat thin red colored burnt clay bricks*

Figure 11 Infrastructure for lime plaster preparation processes and uses

a. *Abandoned lime kiln in Sundarpura, Rajasthan*
b. *Gharat in the fort complex of Kuchaman, Rajasthan*
c. *Walls made up of irregular clumps of Jhanjhra bhatta with a Jhanjhra Bhatta based mortar and plaster at a haveli in Sameliya, Rajasthan*
d. *Araish work on the dado of the garh in Peepla, Rajasthan*

Transported to a location near the site, the quarried lime-rich stone, burnt in a local kiln and then processed further. The slaked lime mixed with fired clay, baked bricks or marble dust was crushed and grounded in a gharat[15] along with a few regional plant-based or animal-based additives; crushed fenugreek seeds, dairy products, various pulses, tree saps, fibres from the *shaan* plant (*crotalaria juncea*). The additives' addition was to enhance the binding properties, usability, accelerate the setting time, water-resistant properties, and the quality of the finishes in the form of lustre, reflection and smoothness of the finished surface. The lime is stored in earthen pots in a well-shaded or dark room to avoid excessive temperature fluctuations. A layer of water is maintained on the surface, and the water is changed periodically till the time it is used in the plaster mix. The idea of using a stale mix, especially for plasters, is a practice seen not only in the region but across the world. Mixes were prepared and left for months and sometimes years before they would be used. Application of the plaster was a long process, involving a number of layers of varied thickness; including a thicker base layer, intermediate layers with reduced thickness and a final fine layer. The composition of the mix and additives are dependent on the layer.

Frescos adorned the exterior surfaces with paintings set in the wet layers of the plaster. The frescoes help create a narrative of the memories that the owner wished to immortalise in paint. The layering of the interior surfaces is a multi-layer smooth finish plaster locally termed as *araaish*[16]. A labour-intensive process, if done

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[15] *Gharat – a stone wheel driven along a circular path by a camel or ox to grind the and mix the aggregates, add mixtures and slaked lime. Also known as chakki locally.*

[16] *Araaish - Araaish is a technique of producing an extremely smooth, glossy and crack-free surface in the final coat of lime plaster or floor finish. It is a mix of quicklime mixed with jhinki (marble dust), gur (jaggery) and methi (fenugreek). The longest lead time is required for the preparation of lime. Post application the lime on the floor is allowed to set and beaten on the floor periodically to remove excess water using a specific branch (use of jaal branches are seen in the region around jaiapur), making it waterproof. The surface plaster and floor plaster are polished with soapstone or hardstone periodically to ensure the gloss and mirror-like effect.*

correctly, could allow one to see the reflection on the wall. The plaster is pigmented using natural plant and mineral-based pigments and finished in geometrical and floral patterns, especially along the dados. The use of lime for flooring and waterproofing in public, residential and royal buildings in the region is a process that involves weeks before achieving the final finish.

Structural systems – walls, beams, brackets and columns

Excavating quarries and searching for the building blocks to build were either a few meters away or a few 50kms away from where the only option was to transport the material on camel backs or bullock carts. Earlier religious buildings in the region, like the Sujanini Devi Temple, Bikaner from around 1170 AD (Pal, 1969), are constructed using intricately carved pillars and beams *(trabeated method of load transfer and construction)* in stone that imported from Jaisalmer.

Other than the traditional load-bearing construction systems where the walls transfer loads of the superstructure to the ground below, extensive use of a hybrid system employing columns and beams in the trabeated form for load distribution and transfer working in cohesion with the load-bearing walls. A construction method perfected and detailed over the centuries in the region and subcontinents religious complexes. Logs of wood or a stone block create a monolithic column or built-up columns using carefully handcrafted pieces of stone or stone or baked brick masonry faced with lime mortar. The adobe buildings' columns are simple and devoid of intricate detailing; columns are either locally sourced wooden log or a *patti* vertically supporting the roof above through a wooden bracket. The more ornate and detailed columns and seen in a structure made up of stone and baked bricks.

Figure 12 Types of columns seen in the region

a. *Composite columns made of adobe bricks and stone pattis in a house Dabbich Gurjan, Rajasthan*
b. *Timber columns in a house in Netsi, Rajasthan*
c. *Fluted stone and brick masonry columns in a haveli in Choru, Rajasthan*
d. *A multi-piece stone column in a baori in baori in Bichoon, Rajasthan*

The earlier column designs are relatively robust square or rectangular columns made up of multiple pieces assembled or using a monolith rock, lined with multi-faced stone brackets supporting the stone lintel and roof above. Later columns reduce the bulk with a change in detailing and shape depending on the use,

advancement in technology and the core material employed in the building. The straight rectangular edges have transformed to create flutes and multi-face columns on a base and more elaborate bracketing.

The use of brackets to support and hold is extensively seen in the trabeated construction. The brackets or *todhi*[17] support and help transfer loads of projecting elements like *chajjas*[18] , beams, *jharokhas*[19] , floors, and spanning openings. The brackets' arrangement, number, type, and form varied from places, with several cultural and religious connotations embedded within the brackets' carving and detailing. Brackets were embedded within the bulky stone walls to support members and provide the possibility of cantilevering. The use of column and beam methods to transfer loads is employed in public, religious, residential and water architecture in the region.

Figure 13 Multiple kinds and uses of brackets

a. *Single-sided brackets supporting the Jharokha of a Burj in the garh at Chittora, Rajasthan*
b. *A series of single-sided brackets supporting a chajja and jharokha in the garh at Kothkhavada, Rajasthan*
c. *A bracketed capitals and wall brackets to support a roof in a house in Khaba, Rajasthan*
d. *Multi-sided bracketed capital of a column supporting the dome of a temple in Mandore, Rajasthan*

The buildings in the region around Jaisalmer extensively used columns with bracketed capitals and multi-faced brackets embedded within the masonry walls to support the timber beams or stone beams that formed the base of the roof. The yellow sandstone found in the quarries in and around Jaisalmer is used for the bracketed capitals, brackets, columns and beams; the shape, size and form of the elements were standardised difference being in the ornamentation of the same.

A couple of inches thick and a couple of feet long stone *pattis* quarried from the region around Jodhpur are seen dotting the landscapes across the region in the form of pavilions. The pavilions were often used as

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[17] *Todhi - a local term given to cantilevering brackets*

[18] *Chajja - A term used for sloping eaves projecting out above the openings, balconies, etc. Sometimes they are isolated to the particular openings or are seen running continuously along the façade of the building.*

[19] *Jharokha -An overhanging oriel window projecting from the walls in the upper storeys of the building supported by brackets or corbelling. The walls of the jharokha in the region are solid with a few openings in the form of windows and jaalis. The make and use were not only for the looks and privacy factors but helped regulate cross ventilation.*

a place for congregation or resting, offering a more permanent solution to the ones made using timber and thatch that were often subject to a termite attack. The use of basic joineries and a trabeated construction form is easy to construct and stable against the forces.

Figure 14 Spatial variation in the use of trabeated construction seen in the region

a. *Semi-open space in a haveli in Jaisalmer, Rajasthan*
b. *Square columns used in a room in a haveli in Amer, Rajasthan*
c. *Patti pavilion constructed using the jodhpuri patti used as a resting place in Bhimapura, Rajasthan*

Figure 15 Use of stone brackets with stone pattis and wooden beams to span spaces

a. *Corner brackets in the walls of a house in Kuldhara, Rajasthan*
b. *The underside of a walkway in the fort complex at Jaisalmer, Rajasthan*
c. *Wooden beams inside a shop in the fort complex at Jaisalmer, Rajasthan*
d. *The underside of a dilapidated roof of a house using wooden beams in Jabaad, Rajasthan*

The spanning of openings in the earlier buildings employed timber or stone lintel; the lintel was either a single log that spans the varying widths of the walls or a series of smaller diameter logs placed in an orderly fashion to transfer the load. The system demanded good quality timber and stone capable of bearing the stresses over a prolonged period. However, this construction system was adequate for smaller and single-storey structures exposed to reduced stresses and was mostly domestic in function and use. The trabeated system increased dependency, and the quality of members governed the opening size.

With the limited availability of load-bearing members and the need for wider openings to allow comfortable movements of men and animals through its bounds, corbeling was a system extensively used in the Indian subcontinent to overcome the limitation. Extensive use of brackets and corbels within the building to support the roof and members by transferring weight to the other reduces the spanning member's size.

Figure 16 Rudimentary form of corbeling seen in the roofs of religious and public buildings in the region.

a. *Corbeling under the dome of the 7th - 8th Century, Harshat Mata Temple in Abhaneri, Rajasthan*
b. *Remains of a corbelled entrance to a temple in fort complex at Mandore, Rajasthan*
c. *The underside of a roof in the Vijay Bagh Baori, Amer, Rajasthan*
d. *Conical roof for a chhatri as part of the Amar Sagar complex in Jaisalmer, Rajasthan*

A construction system where subsequent courses of masonry or building materials overlap each to in an orderly fashion creates an arrangement that helped distribute the loads and stresses as a collective rather than the dependency on a single stone or timber beam or lintel. Corbeling as a system achieved longer horizontal spans by providing additional support. It reduced the unsupported clear span of the load transfer member. Corbeling is used in ceremonial entrances with large spans. In places where flat roofs were not desired, especially in religious or ceremonial buildings, the domical, conical or pyramidal form is achieved using corbelling of stone blocks. The corners of the rectangular space were supported with corbeled pendentives transitioning from a polygonal to a circular form. The corbeled domes use horizontal courses of stone.

Figure 17 Simplified form of corbeling seen in the roofs and as supports in the region

a. *Corbeling in the opening for the Persian wheel system to go through in a Jhalra at Jodhpur, Rajasthan*
b. *Corbelled brackets to supports the floor above for a gateway in the fort complex of Jaisalmer, Rajasthan*
c. *Corner corbelling to support the floor in a private garden complex of Amar Sagar, Jaisalmer, Rajasthan*
d. *The underside of a corbelled dome in a Chhatri at Bhapura, Rajasthan*

Similarly, many ceremonial openings of the various gates within the Jaisalmer fort employed the corbelled brackets embedded within the walls to support the roof and any other storey above it. The shouldered arch[20] is used to span openings in the region, where the stone for the lintel size was restricted. Multi-layered corbeled brackets were used to support the *jharokhas* and roofs/ floors in the *havelis* and forts of Jaisalmer, Bikaner, Jodhpur, Jaipur etc.

The local adaptation of a vaulted roof form or the *dola*[21] roof is seen in places where the longer span stone *pattis* was limited. The is a systematic concentric arrangement over a 3-dimensional plane set in a lime-based mortar that allowed for a formation in the ceiling that helped support the floors above. An extensive system that required skills and an initial formwork to support it during the construction process. The roof above was made of sloping courses and not the true radial courses. (Lancaster, 2015). The concentric circles

[20] *Shouldered arch - A shouldered arch consists of a lintel connected with the jambs of a doorway by corbels. The corbels start with a concave quadrant and continue vertically to meet the lintel. It was used to reduce the unsupported span of the lintel.*

[21] *Dola - A term used for a ceiling type in the region constructed on principles similar to the ones of a radial sail vault.*

were held together by a key called *chabbi*[22]; the concentric conglomerate's number depended on the room's length. The corbeled ceiling is in areas where there is a limitation of long-span *patti*. This roof system is extensively seen in the Shekhawati and the region around Jaipur using baked bricks, irregular stone pieces or the local *jhanjhar bhatta*. The roof's working is similar to the sail vault[23] , a mix of corbeling with a vaulted form transferring the load along multiple axes. The room's length is broken by having multiple sail vaults working in unison to transfer the load. The *dola* roof was used in multiple room orientations, from granaries with a circular plan to rectangular shaped plans of shared and private spaces within a dwelling. The use of the *dola* reduces the dependency on good quality stone and seen in areas that lack good quality stone and timber that could be split and used in the roofs.

Figure 18 Multiple geometries and materials used in the dolas roofs

a. *A domical dola made up of flat bricks set in a mortar in the Soor Sagar complex, Jodhpur, Rajasthan*
b. *Multiple single centre concentric ring of brick along the lengths of the room lined with a brick in between the two sets to span a longer room in a building in Mandawari, Rajasthan*
c. *Multiple single centre concentric ring of stone along the lengths of the room with a stone patti in between the sets to span a longer length in a haveli in Mauzmabad, Rajasthan*

[22] *Chabbi - A term used for a keystone of an arch or vault at the apex holding the elements together.*

[23] *Sail vault - A method for roofing a rectangular chamber, and is a structurally advanced barrel vault since the units are put into compression on two axes, not one.*

Figure 19 Make and finishes of the various types of Dola roofs

a. *A view of a dilapidated haveli showcasing sail vaults made in jhajhara bhatta to transfer the load Sameliya, Rajasthan*
b. *A stone masonry dola in the verandah of a haveli in Mauzmabad, Rajasthan*
c. *Dola roof in the hall Jaigarh fort in Amer, Rajasthan*
d. *Dola roof in a guest entertaining hall in a haveli in Mandawa, Rajasthan*

Structural systems – arches, domes and vaults

In buildings where the spaces' spans are more significant than the standard available size of the material, load transfer was through a series of arches and intermediated columns and beams running along the length and supporting the superstructure. Arches are two corners falling off each other, creating phenomenal strength (Tedx Talks, 2018). A form of construction adapted from the travellers from the west as in central Asia and the earlier forms of rock-cut and timber construction in the Indian subcontinent. Traditionally the trabeated form of construction was widely spread. The arcuate construction method relied on the principles of arches and vaults in coordination with walls to support domes and roofs and transfer the load. It advocated using voussoirs *(stone or brick)* dependent on the mortar, springing from a point and held in place using a keystone. A system that functioned as a single unit with the key being the main junctions holding it together and transferring the load. Initially, the Indian masons were not accustomed to the idea of a building using negation rather than mass. The use of arches was an inhibition for the mason who worked with the well-defined set codes of practice. One often sees a series of blind and fake arches across the region; the original form was a trabeated one, while the arch shape was purely for ornamentation purposes. Eventually, the artisan was led to forging a relationship between the previous and current modes of construction.

Figure 20 Arches designed for the form rather than a structural function

a. *A corbelled trefoil arch in the front and built-up arch in the pol of a temple complex in Amer, Rajasthan*
b. *The cut stone arch is seen in the cenotaphs in Bikaner, Rajasthan*
c. *A built-up arch with a corbelling system and stone members helps give the illusion of a pointed arch at the garh in the Madhorajpura, Rajasthan*

The variation was co-dependent on the influence based on cultural, religious and political relations of the erstwhile kings and their near and distant neighbours; like the trefoil arch, which may be termed as 'Buddhist' because of their similarity in form to the trefoil niches of Gandhara and Pala Bengal (Havell, 1913)(Tillotson, The Rajput Palaces: The development of an Architectural Style, Op.cit). The use of load-bearing arches rather than decorative ones was seen in the later years and replicated in multiple ways and types across the expanse.

Figure 21 Variation in the shapes and forms of arches seen in the region

a. *Semi-circular arch in the garh at Chittora, Rajasthan*
b. *A series of foliated, variation in trefoil and pointed arch in the stepwell in Bhandarej, Rajasthan*
c. *A segmental arch in the stable at Narsinghani, Rajasthan*

As a system, it evolved and used to construct domes and vaults in stone and brick. This method required minimum or limited binding material and could be achieved in dry stone masonry also. Multiple variations are seen in the dome construction in the region. The use of squinches and pendentives, ribs to support the domes and infilling it with masonry to transfer the load to the walls below.

Figure 22 Multiple kinds of vaulted supports

a. *A pointed barrel vault in a gateway in the baori in Panchota, Rajasthan*
b. *The segmental vault of the Bara Mohri in Jaipur, Rajasthan*
c. *A barrel-vaulted passage in the baori in Bhapura, Rajasthan*
d. *The base of a groin vault at the burj near Gatoire ki Chhattriyan, Jaipur, Rajasthan*

Figure 23 Squinches, Muqarnas and pendentives are used to support the masonry domes and half domes

a. *Akhbari Masjid in Amer, Rajasthan*
b. *Burj at the garh in Peepla, Rajasthan*
c. *A chhatri near Sagar in Amer, Rajasthan*
d. *Muqarnas on the entrance to a haveli in Jaipur, Rajasthan*

The use of the arcuated system is seen in the vaulted ceilings and domes. The system was extensively used to create spaces like the *tibaris*[24] and *verandahs*[25], to support the roof or space above. Arched openings were seen in the form of doors, windows and niches along the houses' walls. Arches were used to support spans

[24] *Tibari -A verandah with three openings. The word tibari locally means openings on three sides.*

[25] *Verandah - A roofed partially enclosed area seen as a part of the building opening on to a space with a larger volume. Often used as a transitional and in-between space.*

from a couple of 1m to 25m in the region. Arches were used to provide a column-free large span space with limited availability of good quality stone, used as columns or horizontal beams. A mix of the groin and barrel-vaulted systems is seen in public buildings supporting larger spans. Multiple types of vaults are seen in the *baoris* of the region as part of their pols tier-based transition gateways or the niches in the walls. Domical roofs were extensively used in the ceilings of the *burj*[26] in *garhs* and fortification to support the subsequent floors. Party to the evolution of the arcuated systems of traversing the load through the buildings, the arches were seen supporting water channels in aqueducts across Jaigarh. Similar to the that supported the centuries-old Roman aqueducts. Arches were seen supporting the domes in the form of *muqarnas*[27] that were often used for aesthetic purposes in plaster rather than the ones in stone for load transfer. Arrangements of arches and vaults and domes to carve spaces with more extended and column-free spaces were seen across public, religious, and residential building complexes in the region of study.

Figure 24 Use of arcuated forms through multiples scales

a. *Flat roof pavilions in the garh at Kalwara, Rajasthan*
b. *Pol in a haveli in Mauzmabad, Rajasthan*
c. *Use of arches in niches at the fort in Mandawa, Rajasthan*
d. *A means to transfer load in Toorji ka Jhalara in Jodhpur, Rajasthan*

[26] *Burj - A defensive element of the fort, usually projecting out from the fortification walls. Generally, a tapering semicircular form running along at regular intervals and corners, also acts as a means to provide strength to the fort walls.*

[27] *Muquarna - A three-dimensional decoration of Islamic architecture. Initially structural in purpose, made out of stone, but later on it became of a more crafted decoration and made of plaster, these clusters niches were used to decorate the area between the wall and the dome.*

Conclusion

The dimensions of the spaces directly respond to the building material and skills available in the region. Concepts and practices have been developed and perfected over a period of time. Principles and skills are metamorphized with the refinement in the material palette. Difficulties and shortcomings were overcome using innovation in technology and structural systems. Materials are used in a permutation combination, tailor-made for a situation. Although the palette and landscape vary every few kilometres, a few parameters still make it similar.

In the land where people find it challenging to believe life can thrive, humans have survived for centuries. In the absence is where we find abundance. The regions' buildings are modular but not regimental, thus spatially varying in context and use.

List of Figures

The photos are by the author, other than ones mentioned

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