Journal of History, Archaeology and Architecture
ISSN: 2583-5106, Vol. 5, No. 1, 2026, pp. 89-118

URL: http://www.pbjournals.com/jhaa
Publisher of Open Access Journals
Peer Reviewed Journal

Characteristics of Building Materials used in Someshwar Temple Heritage from South Goa

Laxmi Chagan Yogi and P.D. Sabale
Student, Diploma in Heritage Site Management and Scientific Conservation, Deccan College Post Graduate and Research Institute, Deemed University, Pune (India). E-mail: laxmiyogi0007@gmail.com

Abstract: The material used in the construction of the heritage always decomposes upon exposure over time. Therefore, regular examination of the material is required to understand the strength of the material. The important process to stabilize the deteriorated material as well as washed materials, conservation, and restoration is highly essential. The knowledge of the conservation state of their constituent material is also important to suggest the remedial measures. It includes the intervention plan, the materials, and the techniques to be used. Another important aspect is to understand the physical, chemical, and mechanical properties of the material. To understand these properties, sampling of the building materials and their testing to understand their different characteristics are highly essential. In the present context, the study of the building material of the Shri Someshwar temple complex was conducted in Curdi village of South Goa.

Keywords: Someshwar temple, Submerged heritage, Sedimentology, Material analysis, Doucumentation.

Received : 06 January 2026
Revised : 14 February 2026
Accepted : 25 February 2026
Published : 25 June 2026

TO CITE THIS ARTICLE:

Laxmi Chagan Yogi & P.D. Sabale (2026). Characteristics of Building Materials used in Someshwar Temple Heritage from South Goa. *Journal of History, Archaeology and Architecture,* 5: 1, pp. 89-118.

INTRODUCTION

In general, the heritage structures are characterised by the masonry structure and are built with the pressure principle. Hence, the components of the heritage structures include foundation walls, columns, buttresses, vaults, and domes. In the construction of such heritage on a large scale, naturally dressed stone, undressed stone (natural stone) rubble, cobblestones, brick, etc. were used in the bearing elements (Sami and Ozlem, 2017). The powder of lime and mortar was used as a binding material due to the combination of such fantastic construction material with well-planned construction techniques, resulting in the long life and sustainability of the heritage structures.

But according to the time, some places problems were developed in the structure, especially in the used material, resulting in the structure becoming abundant. Therefore, it is necessary to apply / employ the recently developed conservation techniques for the repair and strengthening of the heritage structure. In which the restoration of heritage structures and the control of the adequacy of the barring system are two of the most important parts of the structure needed to examine property. Hence, a detailed study in the field and a lab experiment on the building material are required to understand all its characteristics, which determine the present status of that particular heritage.

AIMS AND OBJECTIVES

The aims and objectives of the research are as follows: **i)** to document the temple complex systematically; ii) identify the chemical and mineralogical composition; iii) understand the art and architecture of temple heritage; iv) record the detailed observations of each element of temple heritage to understand its dimension, history, and importance; v) collect the representative samples of each building material for lab analysis to fulfill the aims and objectives; vi) understand the effect of pyro-technology on mineral characteristics; vii) identify the minerals present in the samples by using XRD; viii) understand the particle size and shape of the sediments; and ix) based on various lab tests, understand the nature and province of the raw material from which it is derived.

STUDY AREA

Curdi is located in the Sanguem tehsil of South Goa, within the catchment area of the Salaulim Dam. Prior to submergence, Curdi was a flourishing agrarian and ritual settlement. The site is accessible by

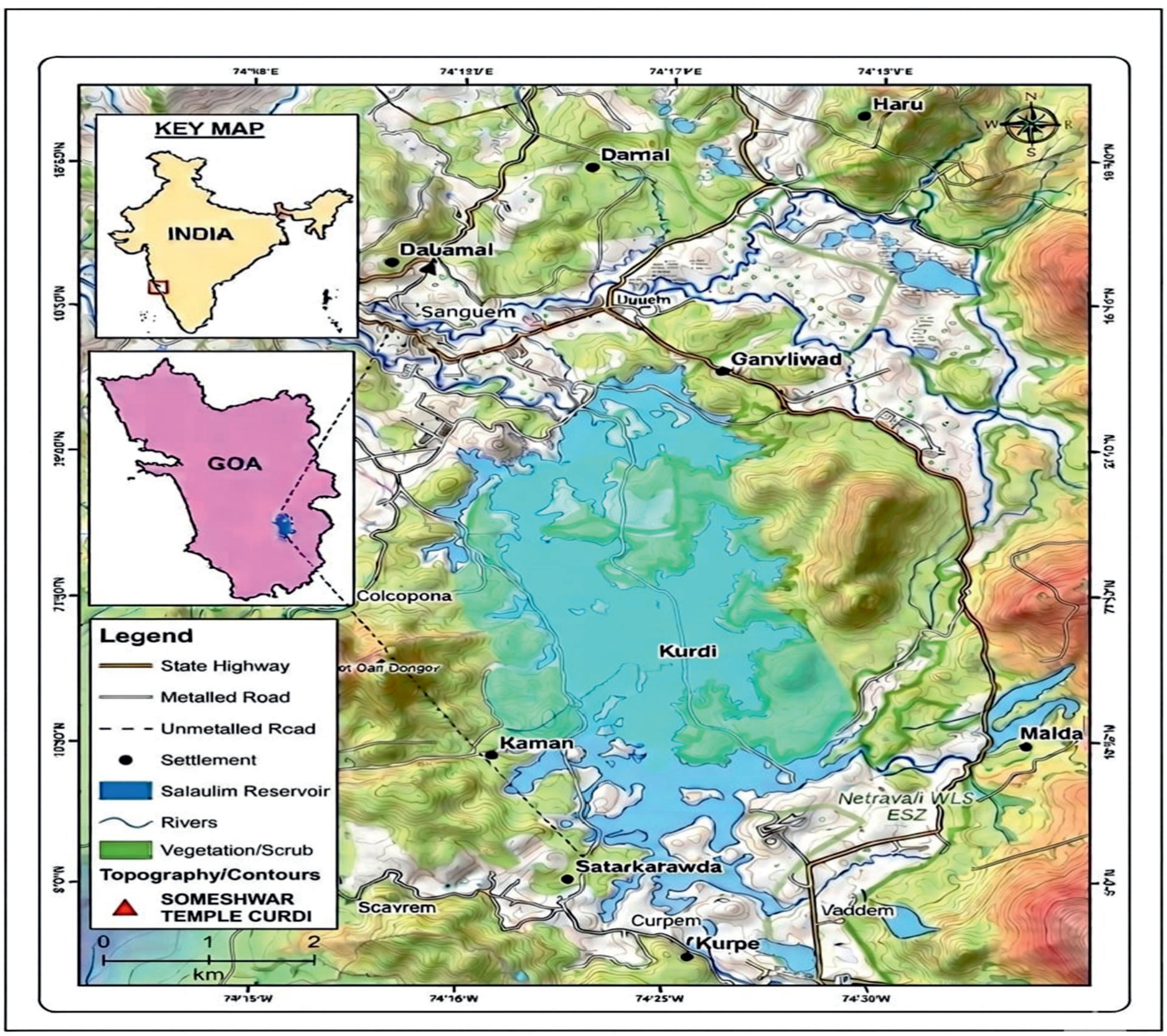


Fig. 1: Location and topography map of the study area (Modified after, Kathiresan et al., 2017).

two routes. It is 66km away from Panjim towards Margao via NH-66. Then go from Margao to Quapem via SH-6 until you reach Sanguem; from there, take the Salaulim Dam road. The temple is about 6-7 km via mud road in the Curdi reservoir. ii. It is accessible by another route, i.e., from Margao, take the Margao-Curchorem road 32 km, continue on the Curchorem-Ponda road towards Rivona, and from there take Kurpem Road and follow the Curdi backwater road till you reach the temple.

TOPOGRAPHY

The study of Salaulim Dam is a part of South Goa. It is undulating to plan a topographical area of deeply eroded lateritic terrain shows rolling topography. It has the well-defined boundaries of the Sahyadri escarpment, the Western Ghats on the northern side, and the west coastal stripe of the Arabian Sea on the south. The area shows low elevated hills and hillocks and is bounded by a nearly plain to sloppy surface, which is used as a paddy field. At places very shallow to moderately deep natural depressions are found; most of these are well connected with the string channels. The stream channels are mostly filled with fine to medium size sediments which are formed due to the devastating denudation action on the exposed lateritic duricrust (Fig. 1).

As far as the geology is concerned, the area consists of thin and thick flows of basaltic rock of the Deccan trap formation. Due to the weathering, erosion, and leaching effect on the basaltic rock and the high-humid climate, laterite is formed. The laterite is exposed all along the area on the surface. The Dharwar supergroup of the Archaean formation of Proterozoic age is also present. Similarly, the granite-gneiss, felspathic gneiss, hornblende granite, and porphyritic granite. The soil found in this area is lateritic soil, which is formed by weathering and erosion of laterite (Singh et al., 2023).

FIELD INVESTIGATION

Detailed fieldwork was carried out during the seasonal exposure of Curdi, when water levels recede sufficiently to access the temple. The methodology used for this work is described as follows.

During the field survey, a systematic documentation of the temple heritage and its complete complex was carried out. During the documentation of this structure, the following points are taking on a priority basis, which include i. Mapping visible structural features of the temple observed in the complex; ii. Examination-associated elements such as the *deepastambha* and *Natyagruha; iii.* Recording remains of former residential structures, such as shops, police stations, and houses on the premises of the temple; iv. Photographic and videographic recording of important parts of heritage; and v. Recording of each corner of heritage and sample locality with GPS.

COMMUNITY CONSULTATION

Informal discussions with former residents provided, which include, i. identification of structural components; ii. timeline of additions/repairs; iii. information on materials used pre-submergence and iii. Dating clues for ceramics and modern building materials.

BUILDING STONE USED

There are three types of building stones, as mentioned above: i. dressed; ii. partially dressed; and iii. Undressed stones, which were used in the construction of temple heritage.

a b.

Fig. 2: Shows a. *Deepstambh and* **b**. *Tulsi Vrindavan* **near the temple complex**.

In the above figure 2, we can see the structure of *Deepstambh* and *Tulsi Vrindavan*; it was built with the use of laterite stone, which was naturally dressed and hand-chiseled into intricate carvings.

a b.

Fig. 3: Shows a. Shri Someshwar temple and b. drama theater (*Natyagruha***).**

As we can see in the figure 3, the construction of the Shri Someshwar temple and *Natyagruha* was done with the use of naturally partially dressed laterite stone, which was hand-chiseled mostly in rectangular or block-like forms. This technique was carried out throughout the construction of the temple and drama theater from the foundation till the garbhagriha.

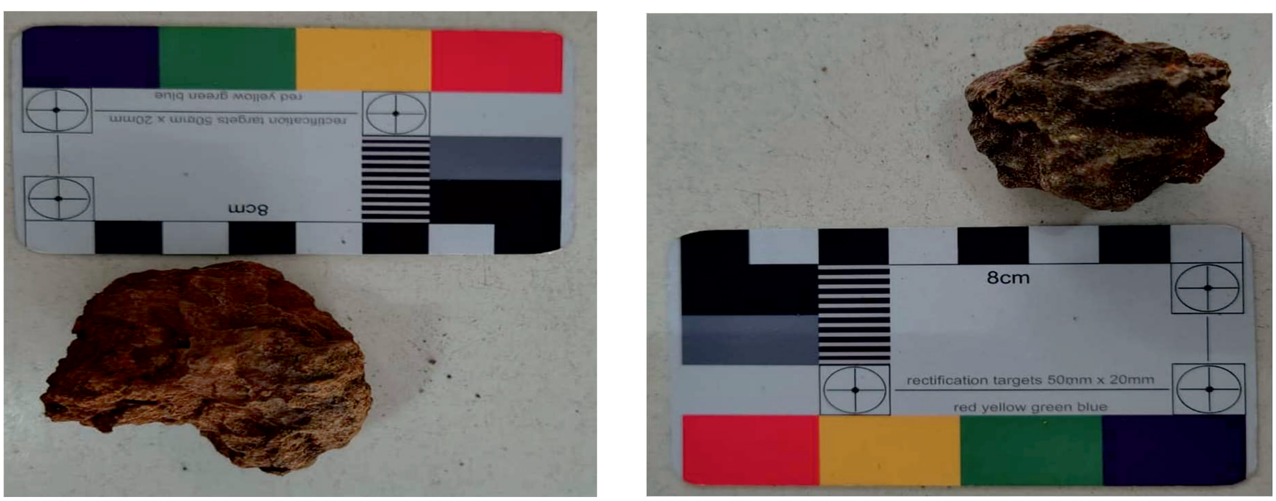
The construction of this house was done with the use of laterite stone in a naturally dressed form, which has been hand chiseled, which we can see in the disintegrated wall on the left side of the figure, and also the use of undressed stone, which we can see on the right side of the figure, which has been disintegrated around the area (fig. 4).

Fig. 4: The deteriorated house of curdi.

NATURE OF SAMPLE COLLECTED

For lab analysis purposes, three categories of materials were collected from the field site. This includes i. Roof tile fragment to know its basic material used for the manufacturing and chemical composition; ii. lime samples were collected to understand the proportion of lime and mortar in the binding materials; iii. A mud plaster sample to understand the nature of the shape and size of the soil and its sources and also two refined ceramic sherds were collected for the analysis. The details of each sample collected from the site is as given below.

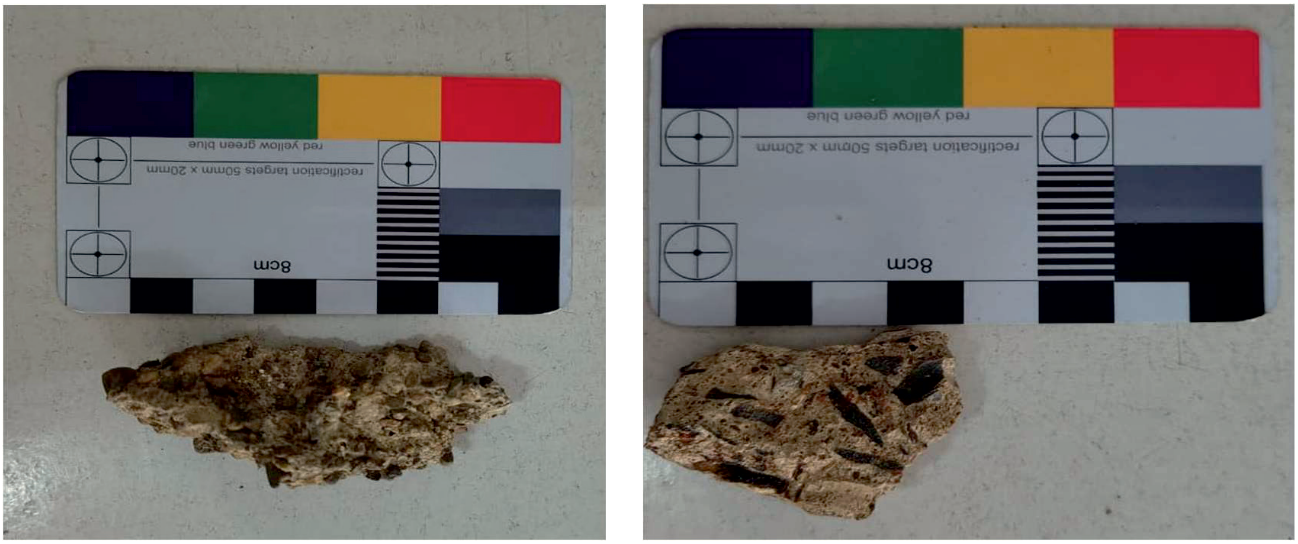
(a) Mud sample: Collected from collapsed domestic wall remains composed of mud and mortar. The sample context indicates typical household construction using locally sourced soil.



a. b.

Fig. 5: Shows a. and b. are mud-brick samples and sample b is used for sedimentological analysis analysis.

(b) Lime sample: Recovered from a partially intact structure near the central open area. The presence of lime suggests modification or later constructions prior to complete village evacuation.



a. b.

Fig. 6: Shows lime samples a and b collected from Curdi site.

Fig. 7: Shows a lime mortar sample from Curdi.

(c) Roof tile fragment: One of the most informative finds from Curdi was a **roof tile fragment** recovered near the site of the police station. Roof tiles are durable indicators of material culture, as they combine **local clays, temper, and firing techniques.**

Fig. 8: Roof-tile fragment submitted for XRD testing

(d) Ceramic fragment: Multiple pottery fragments were located in domestic zones. They represent utilitarian wares: storage pots, cooking vessels, and water pots.

a. b.

Fig. 9: a and b shows ceramic fragments collected, displayed with a measurement scale.

Laboratory investigations

Material analysis aimed to understand construction quality, technological traditions, and environmental impacts on site preservation.

Pyro-technology analysis

Table 1: Pyro-technology analysis of the sample. 1. Ceramic; 2. Roof-tile; sample-3. Lime; sample-4. Mud; sample 5. Lime and mortar and sample 6. Lime.

Sr. No.	*Sample No.*	*Initial Weight*	*Temp. 150°C*	*Temp. 200°C*	*Temp. 400°C*	*Temp. 700°C*	*Temp. 900°C*
1	1	10g The initial color of the sample was dark reddish white.	10g	10g	10g	9g	9g:The color changed from reddish brown to light red brown.
2	2	10g The initial color of the sample was whitish grey.	10g	10g	10g The color changed from whitish grey to light grey.	9g Colour changed from light grey to whitish.	9g Colour changed from whitish to pink.
3	3	10g Initial colour of the sample was light grey.	10g	10g	9g Colour changed from light grey to dark grey.	9g	8g Colour changed from dark grey to dark grey red.
4	4	10g Initial colour of the sample was light reddish brown.	9g	9g	9g Colour changed from light reddish brown to dark reddish brown.	8g Colour changed from dark reddish brown to brick red.	8g

Sr. No.	*Sample No.*	*Initial Weight*	*Temp. 150°C*	*Temp. 200°C*	*Temp. 400°C*	*Temp. 700°C*	*Temp. 900°C*
5	5	10g Initial colour of the sample was dark red.	10g	10g	10g Colour changed from dark red to light red	10g Colour changed from light red to lighter red.	10g Colour changed from lighter red to light brick red.
6	6	10g: The initial color of the sample was light gray.	10g	10g	10g	10g Colour changed from light grey to dark brown.	10g Colour changed from dark brown to greyish brown.

Sieve analysis

Sieve analysis is a method used to determine the particle-size distribution of a material by passing it through a series of sieves with different mesh sizes. It helps identify whether the mud or mortar used in construction was fine, coarse, or mixed, which affects strength, binding ability, and durability. This test is important because particle size strongly influences how materials behave under moisture, pressure, and weathering. Without sieve analysis, it becomes difficult to understand construction quality or compare materials from different structures, limiting accurate interpretation of building technology.

Table 2: Sieve Analysis of Samples: 1. Ceramic, 2. Roof tile, 3. Lime, 4. Mud, 5. Lime 2, 6. Mud 2, 7. Lime and Mortar, and 8. Lime 3.

Sieve Analysis		*4mm*	*2.8mm*	*1.70mm*	*1.40mm*	*850mics*	*500mics*	*425mics*	*150mics*	*75mics*	*Pan*
Sample NO.	Initial weight										
1	20g	00	00	00	00	2g	4g	2g	6g	3g	3g
2	60g	9g	7g	9g	4g	8g	4g	3g	7g	5g	4g
3	40g	00	8g	4g	8g	2g	4g	3g	5g	3g	3g
4	60g	7g	3g	4g	13g	4g	8g	7g	10g	3g	1g
5	8g	0	0	0	0	1g	2g	1g	2g	1g	1g
6	11g	0	0	0	0	0	1g	1g	2g	3g	4g
7	20g	3g	1g	3g	1g	3g	2g	1g	3g	1g	2g
8	13g	5g	3g	1g	580mg	20mg	1g	440mg	1g	430mg	550mg

Ceramic sample

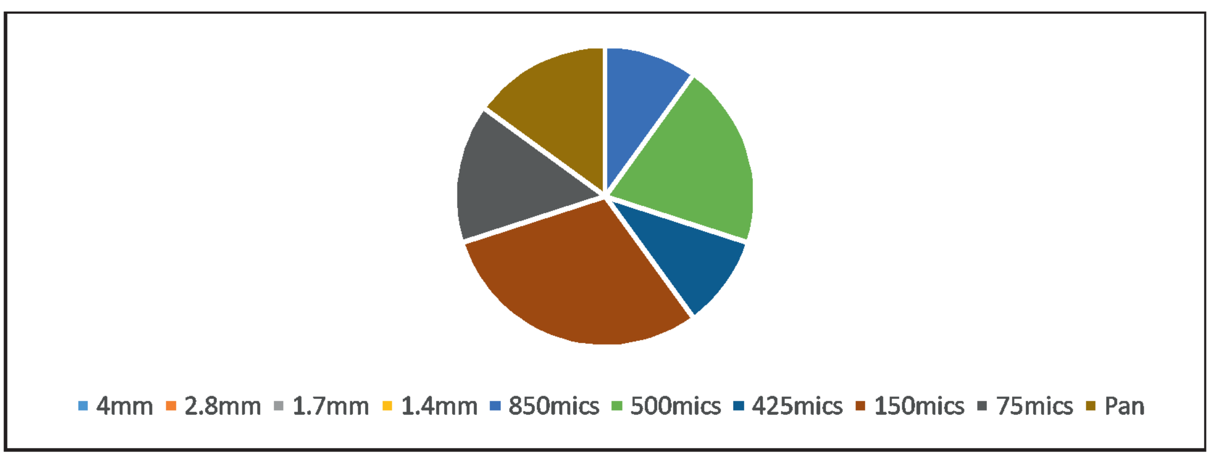


Fig. 10: Grain size distribution – ceramic sample.

Interpretation

The ceramic sample displays a fine sediment composition, with no coarse particles retained in larger sieve sizes. The dominance of medium-to-fine fractions (150–500 microns) indicates the use of refined clay, likely processed to remove impurities. This grain-size distribution suggests careful clay processing and intentional removal of coarse particles suitable for ceramic production.

Roof-tile

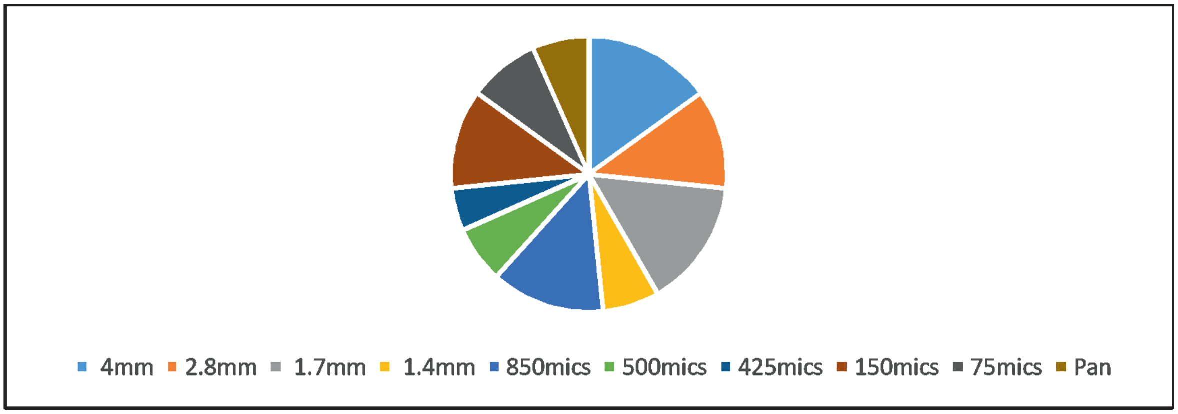


Fig. 11: Grain size distribution – roof-tile sample.

Interpretation

The roof-tile sample shows a mixed grain-size distribution, with substantial material retained across both coarse and fine sieves. The highest retention occurs in the 4 mm and 1.70 mm fractions (15% each), indicating the presence of coarse inclusions. Finer particles below 150 microns are also present but in lower proportions. Indicating the intentional addition of coarse temper. This composition suggests the material was prepared for structural strength rather than surface refinement.

Lime sample

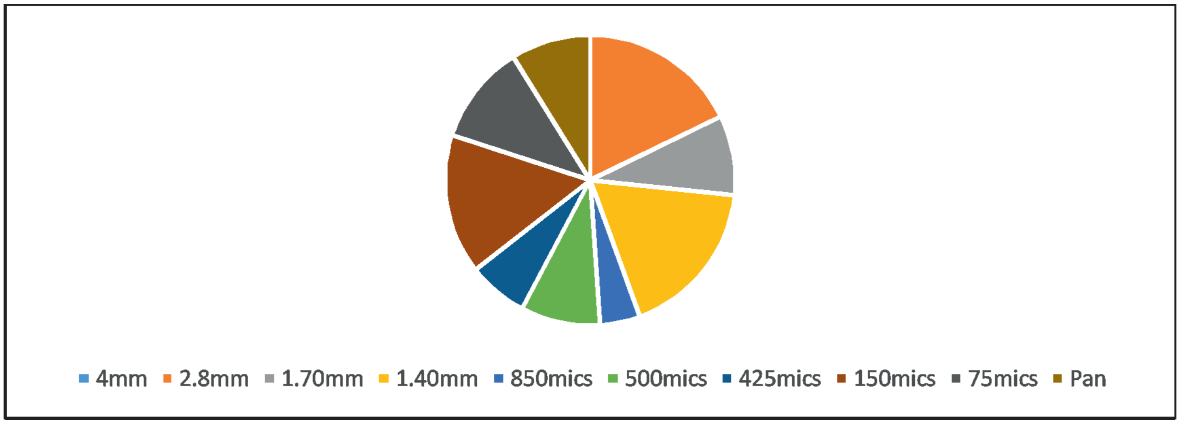


Fig. 12: Grain size distribution – lime sample.

Interpretation

(i) The lime exhibited a **heterogeneous grain size**, with dominance of coarse particles at 2.36 mm and 1.40 mm.

(ii) This suggests the use of **locally mixed lime mortar**, not industrially standardized Portland lime.

(iii) The presence of both fine and coarse particles reflects a traditional practice of combining **river sand or crushed laterite** with lime.

(iv) The variability in grain size implies **on-site preparation rather** than pre-mixed materials.

The lime sample shows a moderately graded fine-to-medium sand mix, typical of mid-late 20th century construction. This suggests the lime represents later repair or extension work—possibly around the 1970s–1980s, before village abandonment.

Mud plaster sample

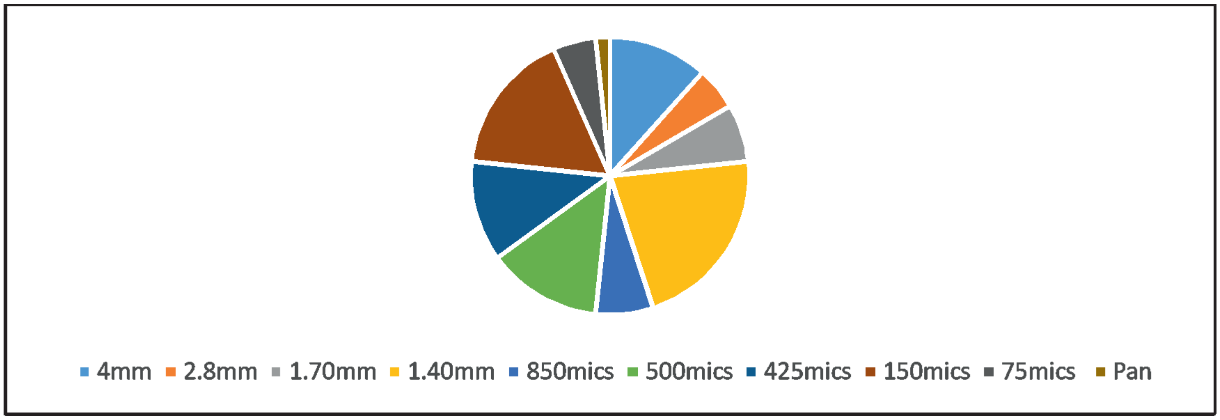


Fig. 13 Grain size distribution – mud sample.

Interpretation

- The mud shows dominance of **fine particles (below 600 µm),** accounting for ~25% of the sample.
- This composition is consistent with **lateritic soils,** rich in iron oxides and fine clays.
- The mixture likely included **rice husk, straw, or cow dung** as tempering agents, improving cohesion and thermal insulation.
- The absence of standardized grading confirms **vernacular building traditions**, in contrast to lime-based mortars.

Lime sample-2

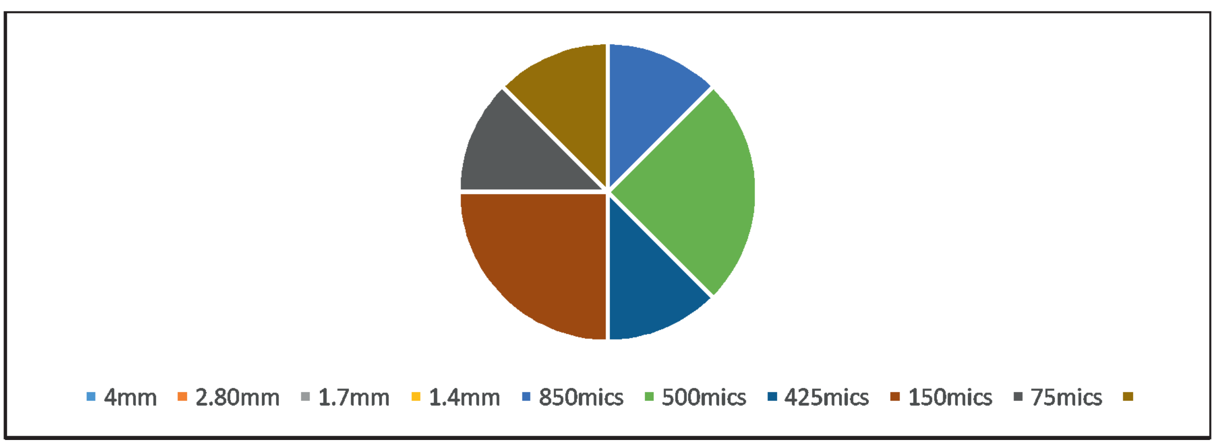


Fig. 14: Grain size distribution – lime sample-2.

Interpretation

The lime sample shows a fine-grain composition, with no material retained in sieves above 1.40 mm. The highest percentages occur in the 500 microns and 150 microns fractions (25% each), indicating controlled processing likely through careful slaking and sieving. Such composition is suitable for plastering and finishing applications.

Mud brick sample-2

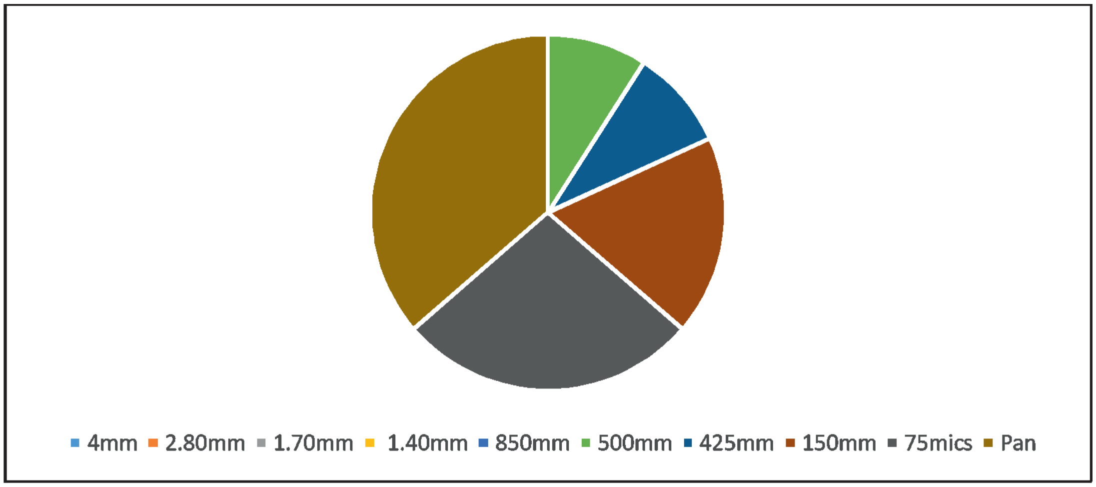


Fig. 15: Grain size distribution – mud sample-2.

Interpretation

It shows a completely fine-grained composition, with no material retained above 500 microns. Nearly 64% of the sample falls below 150 microns, indicating a high proportion of clay-sized particles. This confirms its suitability for plastering applications while also explaining its vulnerability to moisture-induced decay.

Lime and mortar sample

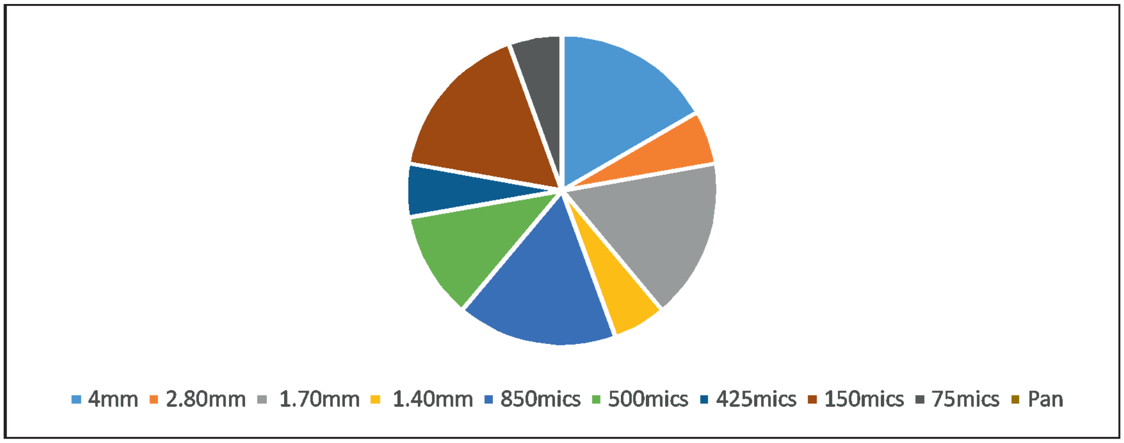


Fig. 16: Grain size distribution – lime and mortar sample.

Interpretation

The sieve analysis indicates a mixed-grain composition, with material distributed across coarse, medium, and fine fractions. Significant retention at 4 mm, 1.70 mm, and 150 microns suggests the presence of both aggregate and fine binder. This analysis reflects a durable lime mortar designed to provide strength.

Lime sample-3

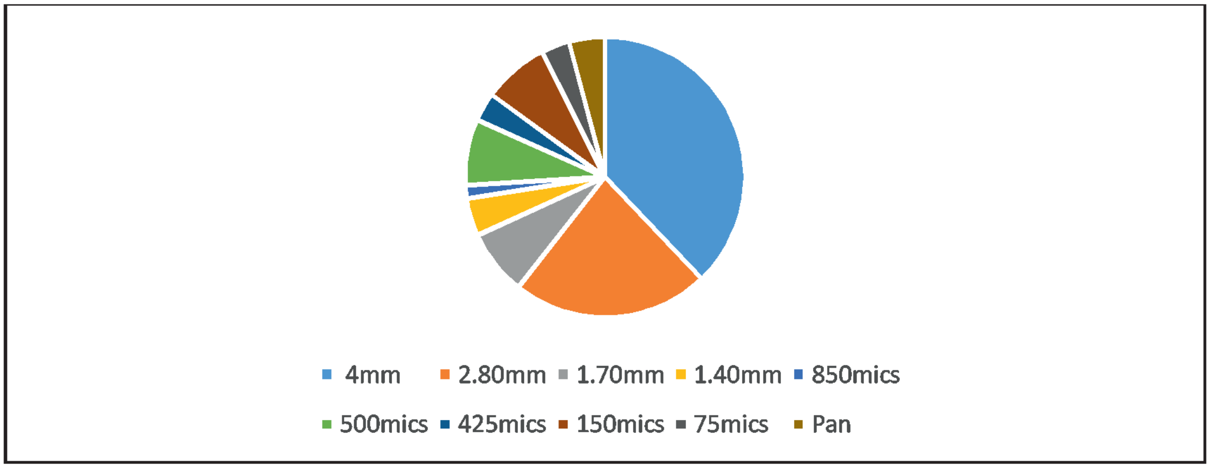


Fig. 17: Grain size distribution – lime sample-3.

Interpretation

The sieve analysis indicates a predominance of coarse material, with over 60% of the material found above 2.8 mm. The low percentage of fine particles suggests limited binder content, pointing to its use as a structural lime rather than a finishing plaster. The material would have provided durability and resistance.

Shape analysis

Shape analysis examines the form of grains—whether they are angular, sub-angular, rounded, or well-rounded. Grain shape affects packing density, bonding strength, and the overall stability of construction materials like mud mortar and lime. This test is important because angular grains create strong interlocking structures, while rounded grains reduce friction and weaken bonding. If shape analysis is not conducted, the mechanical behavior and preparation quality of the construction material cannot be properly understood, leading to incomplete conclusions about structural performance.

Table 3: Shape analysis of samples: 1. Lime, 2. Lime 2, 3. Lime and Mortar, 4. Lime 3 and 5. Mud.

Shape Sample No.	*Very Very Angular*	*Very Angular*	*Angular*	*Sub-angular*	*Sub-rounded*	*Rounded*	*Well Rounded*	*Very Well Rounded*
1	00	00	07	46	45	02	00	00
2	00	02	20	35	25	00	00	00
3	02	14	41	35	08	00	00	00
4	08	09	37	29	17	00	00	00
5	00	00	03	63	34	00	00	00

Lime sample

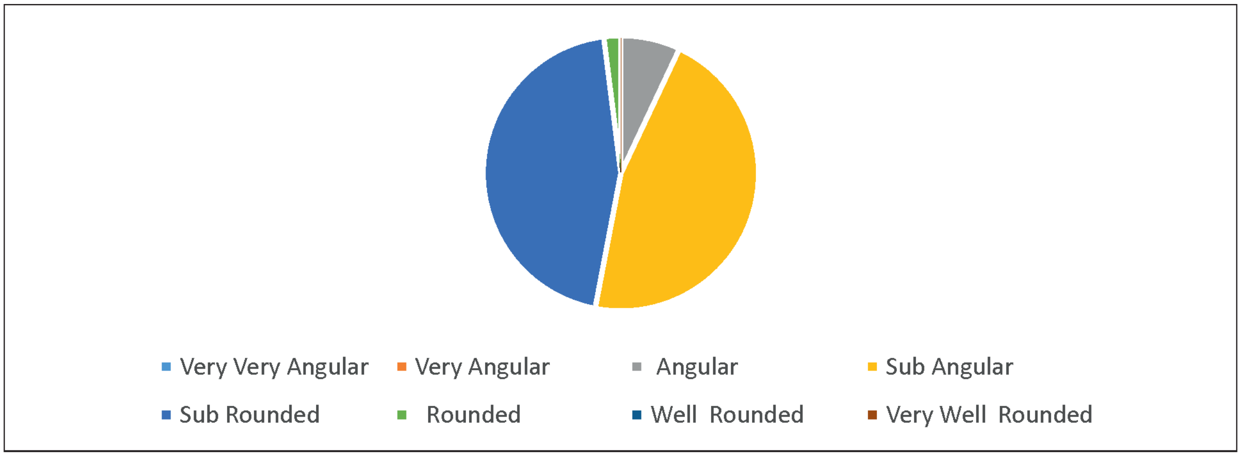


Fig. 18: Shape distribution—lime sample

Interpretation

The dominance of **sub-angular and sub-rounded grains** suggests aggregates derived from **river sands or weathered laterite,** minimally processed. The presence of angular particles reflects crushed local stone added to the mix.

Lime sample-2

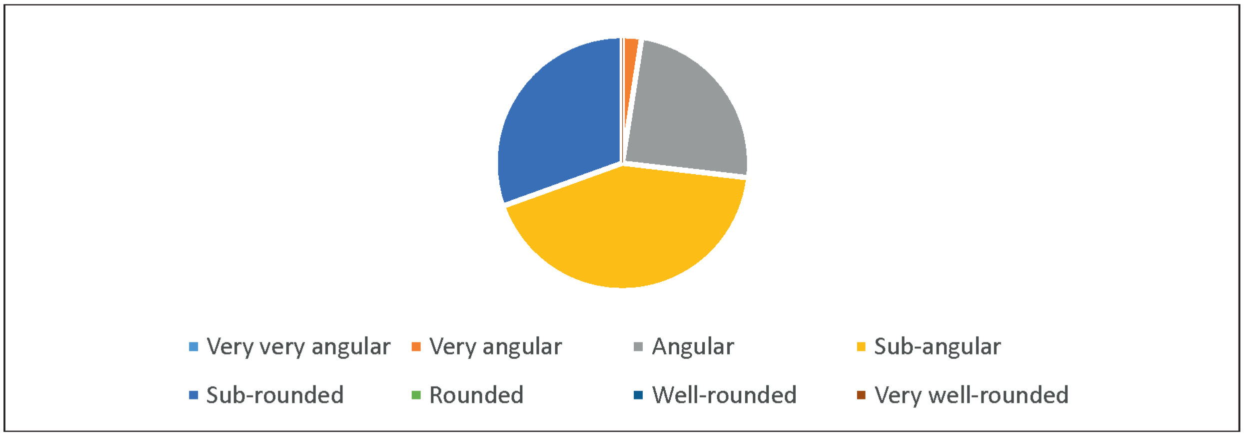


Fig. 19: Shape distribution – lime sample-2.

Interpretation

It shows a clear dominance of sub-angular (35%) and sub-rounded (25%) grains, together forming the major component of the aggregate. This distribution indicates that the material was derived from naturally weathered sources, such as riverine ones. The presence of a significant proportion of angular (20%) and very angular (2%) particles further points to the intentional addition of crushed local stone or limestone fragments to the lime mix.

Lime and mortar

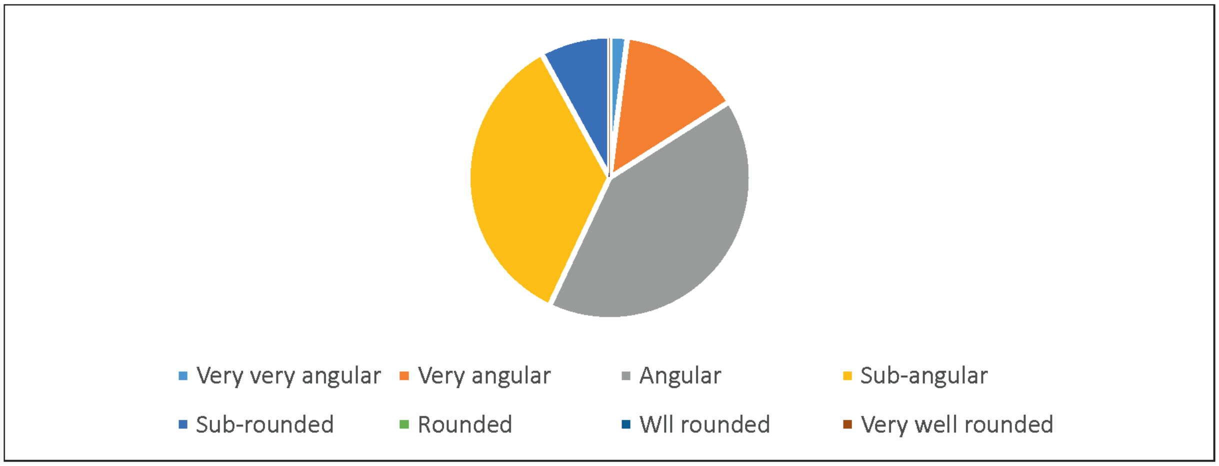


Fig. 20: Shape distribution – lime and mortar sample.

Interpretation

The lime and mortar sample has more angular (41%) and sub-angular (35%) grains, together comprising the majority of the sample. While the remaining grains comprise very angular (14%), very very angular (2%), Sub-rounded (8%), and no rounded and well-rounded grains are observed. This distribution indicates poor rounding and suggests that the grains have undergone little transport and weathering.

Lime sample-3

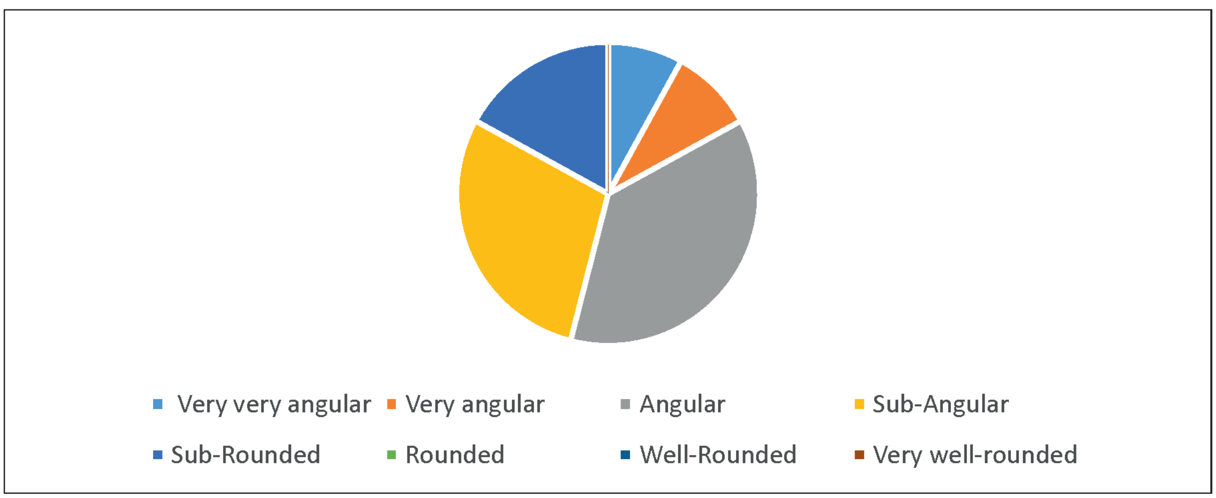


Fig. 21: Shape distribution – lime sample-3.

Interpretation

The lime sample has more angular (37%) and sub-angular (29%) particles, which together constitute the majority of the sample. The remaining grains comprise sub-rounded (17%), very very angular (8%), and very angular (9%), with no rounded, well-rounded, or very well-rounded grains found. Overall, the sample reflects poor rounding and suggests a nearby source area.

Mud brick sample

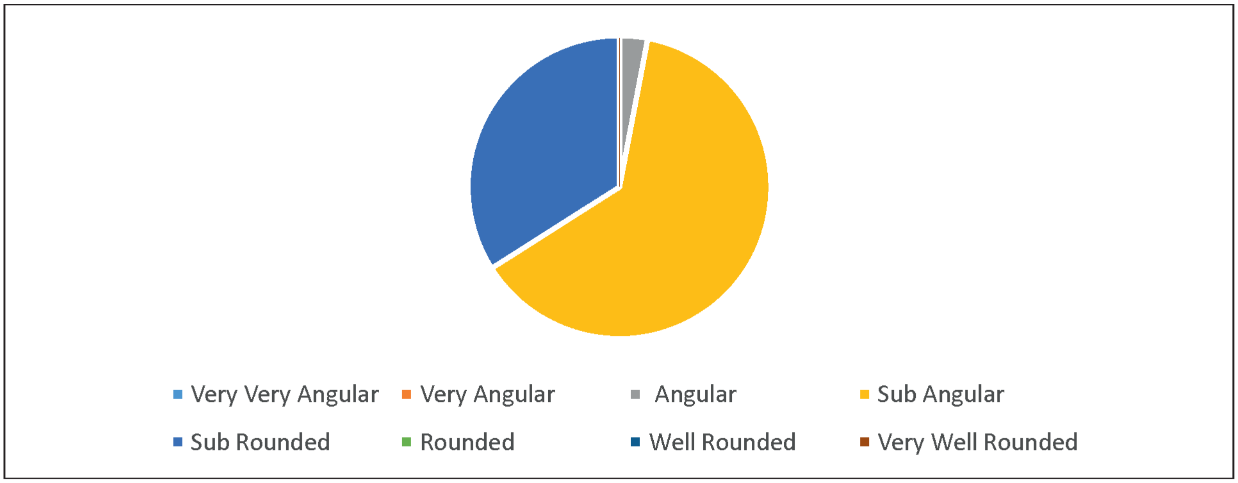


Fig. 22: Shape distribution – mud sample.

Interpretation

The overwhelming presence of **sub-angular grains** indicates the use of **locally sieved lateritic soils,** with minimal transport or reworking. This points to **in situ material use**, where villagers relied on soils directly from their fields or nearby slopes.

Comparative interpretation

The material evidence reveals a **hybrid construction tradition** at Curdi: i. **Vernacular practices:** Mud mortars with fine lateritic soils, tempered with organics, used in ordinary houses; ii. **Portuguese influence:** Seashell lime and standardized tile sizes, visible in temple structures and public buildings; iii. **Modern adaptations:** Lime mortars with mixed aggregates, likely introduced in the mid-20th century.

This hybridization reflects Curdi's **long history of cultural negotiation** between indigenous Goan traditions, colonial inputs, and modern materials. It also explains the uneven preservation of structures: i. **Mud houses** collapsed rapidly under submergence; ii. **Lime-based structures** (police station and shops) resisted longer but still fractured under repeated waterlogging; iii. **Temples built of laterite and lime** endured best, though heavily eroded.

X- Ray Diffraction (XRD) analysis

XRD is a technique used to identify the mineral composition of a material by measuring how X-rays scatter when they strike crystal structures. It helps determine what minerals are present in roof tiles, mortar, or clay, revealing the source of raw materials and the firing or formation conditions. This test is crucial for understanding durability, weathering response, and traditional manufacturing techniques. Without XRD, the mineralogical identity of the materials remains unknown, making it impossible to explain their long-term behavior or vulnerability to submergence-related decay.

Laboratory analyses underscore this hybridity

Roof tile Goa-evaluation report
Measurement Conditions

Table 4: Measurement Conditions of Roof Tile Goa.

X-Ray generator	*40 kV, 15 mA*	*Scan mode*	*1 D (scan)*
Incident primary	No unit	Scan speed/Duration time	5.00 °/min
Goniometer	Mini Flex 300/600	Step width	0.01 °
Attachment	Standard sample stage	Scan axis	θ/2θ
Filter	None	Scan range	3 ~ 60 °
Selection slit	None	DS	1.25 deg
Diffracted beam mono	None	IHS	10 mm
Detector	D/text Ultra2	SS	Open
Optics attribute	None	RS	Open

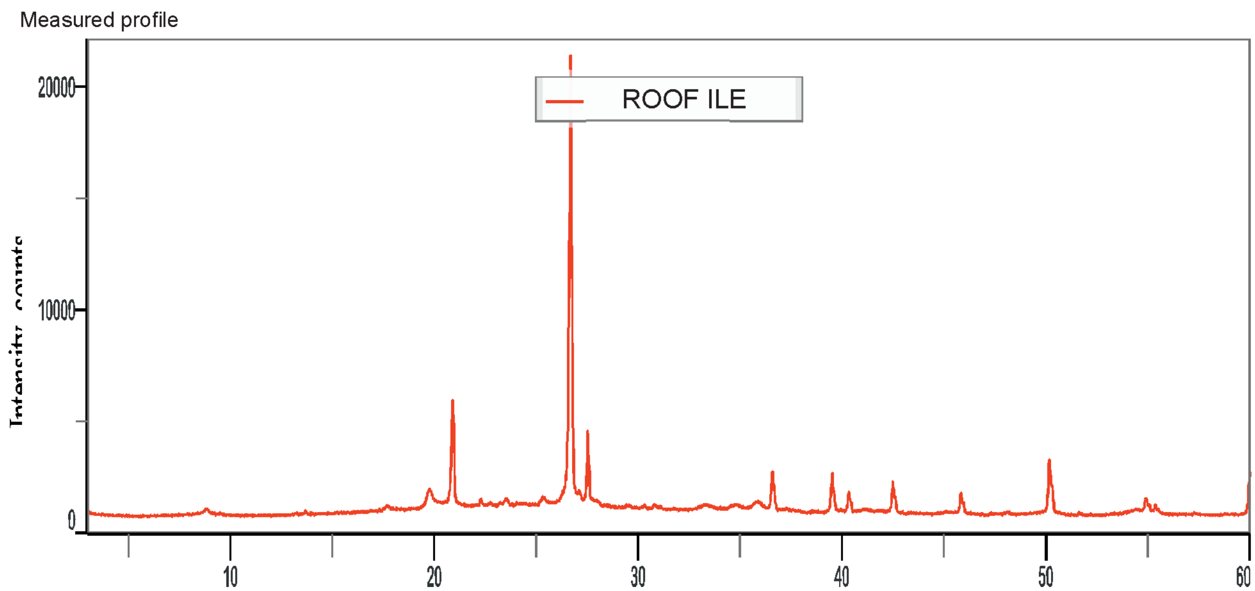


Fig. 23: XRD measured profile view.

Peak evaluation conditions

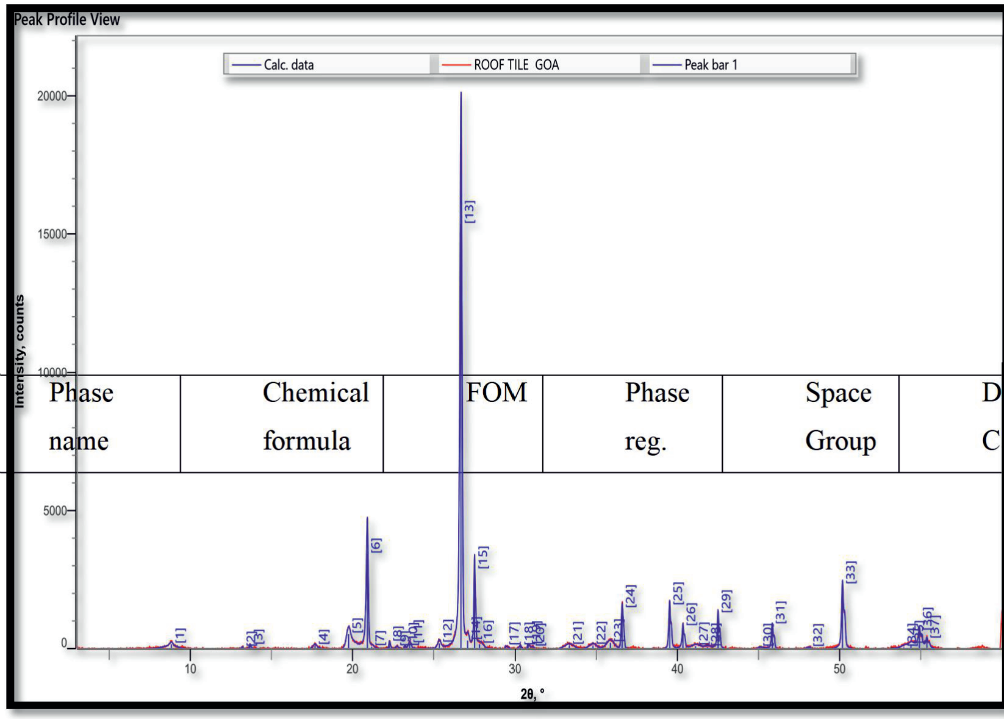
Table 5: Peak evaluation condition

Peak search method	*Second derivative method*	*σ cut*	*3.00*					
Profile fitting	Run completed	Peak shape	Split pseudo-Voigt		Fitting condition			Auto (Refine background)

Table 6: Qualitative analysis results of roof tile

Phase name	*Chemical formula*	*FOM*	*Phase reg. detail*	*Space Group*	*DB Card Number*
Si O2	O2 Si	0.541	S/M: COD	152: P3121	1526860
Albite	Al Na O8 Si3	2.918	Import: COD	2: C-1	9000530
Muscovite 2M1		2.037	Import: COD	15: C12/c1	1100013

The XRD results show that the roof tile is made from locally sourced clay rich in **quartz, albite, and muscovite,** minerals typical of Goan lateritic soils. This confirms that the tile was produced using **local vernacular materials and traditional firing methods.**



Phase name	Chemical formula	FOM	Phase reg.	Space Group	DB Card

Fig. 24: XRD peak profile view of a roof tile.

Qualitative analysis results

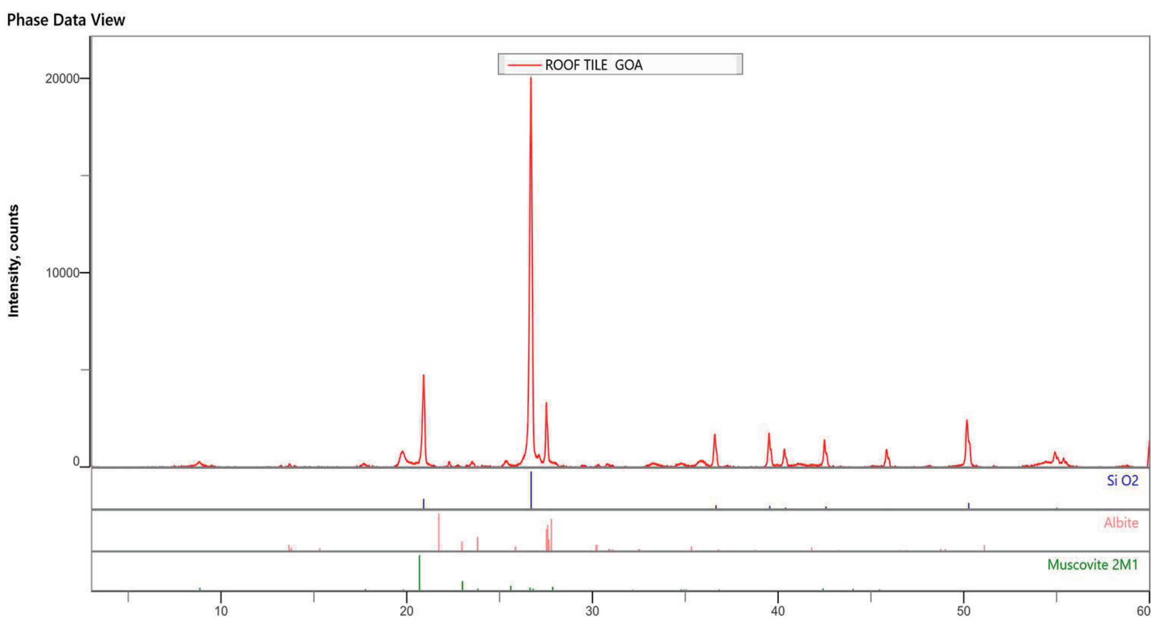


Fig. 25: Phase date view report of roof tile.

Lattice parameters

Table 7 XRD report of roof-tile sample showing lattice parameters.

Phase name	*a, Å*	*b, Å*	*c, Å*	*α, °*	*β, °*	*γ, °*
Si O2	4.91589	4.91589	5.40820	90.000	90.000	120.000
Albite	8.28159	12.96758	7.15087	90.097	116.092	89.988
Muscovite 2M1	5.23869	9.12219	20.26703	90.000	95.500	90.000

The lattice parameters show that quartz (SiO_2) has equal a and b values and a γ angle of 120°; Albite displays a noticeably high β angle (116.09°); and Muscovite shows a very large c value (20.26 Å) and a β angle of 95.5°.

1. Roof tiles (XRD analysis): The roof tile fragment subjected to X-ray diffraction revealed a composition dominated by quartz, albite (feldspar), and muscovite (mica). These phases indicate the use of lateritic clays enriched with feldspathic minerals, sourced locally. The persistence of muscovite and albite suggests incomplete vitrification, characteristic of traditional kiln firing with uneven temperatures, rather than industrial uniformity. This confirms that the tile was locally produced using vernacular technology, representing continuity in Konkan roofing traditions.
2. Sieve and shape analyses revealed variability in particle sizes, confirming on-site, non-standardized preparation.

   This combination reflects a community negotiating continuity and change, balancing indigenous practices with colonial technologies and modern materials.

   The XRD analysis revealed the following mineralogical composition:

   (i) Quartz (SiO_2): Dominant phase, providing strength and durability.

   (ii) Kaolinite ($Al_2Si_2O_5(OH)_4$): Clay mineral indicating low- to medium-temperature firing.

   (iii) Hematite (Fe_2O_3): Source of the reddish color, linked to lateritic iron oxides in the raw material.

   (iv) Minor feldspars: Suggesting natural inclusions from local soils.

This evidence aligns with broader Goan practices where **terracotta roof tiles** were the norm, only later supplemented by **Mangalore tiles** introduced through trade.

Sample lime-1: evaluation report

Measurement Conditions

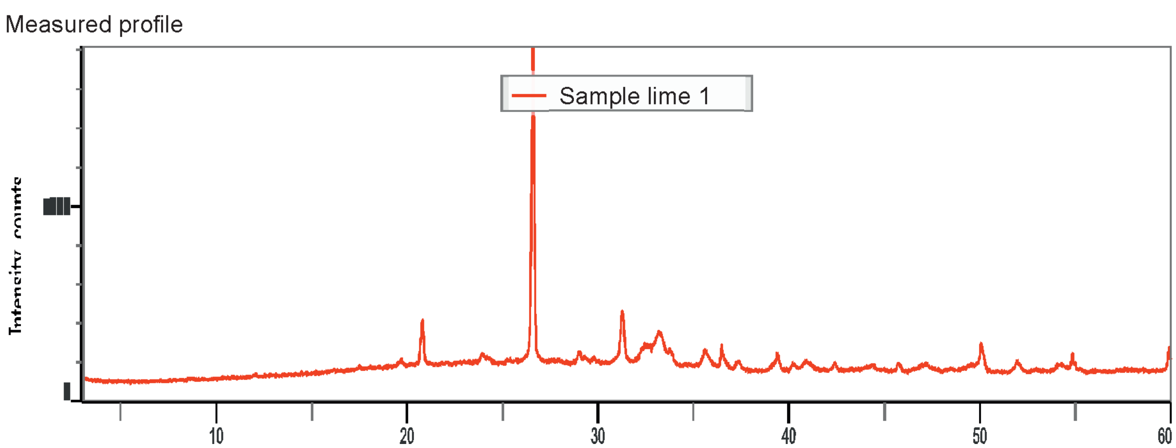


Fig. 26: Measured profile of lime sample-1.

Table 8 Measured condition of lime sample-1

X-Ray generator	*40 kV, 15 mA*	*Scan mode*	*1 D(scan)*
Incident primary	No unit	Scan speed/Duration time	5.00 °/min
Goniometer	MiniFlex 300/600	Step width	0.01 °

X-Ray generator	*40 kV, 15 mA*	*Scan mode*	*1 D(scan)*
Attachment	Standard sample stage	Scan axis	θ/2θ
Filter	None	Scan range	3 ~ 60 °
Selection slit	None	DS	1.25 deg
Diffracted beam mono	None	IHS	10 mm
Detector	D/teX Ultra2	SS	Open
Optics attribute	None	RS	Open

θ, °

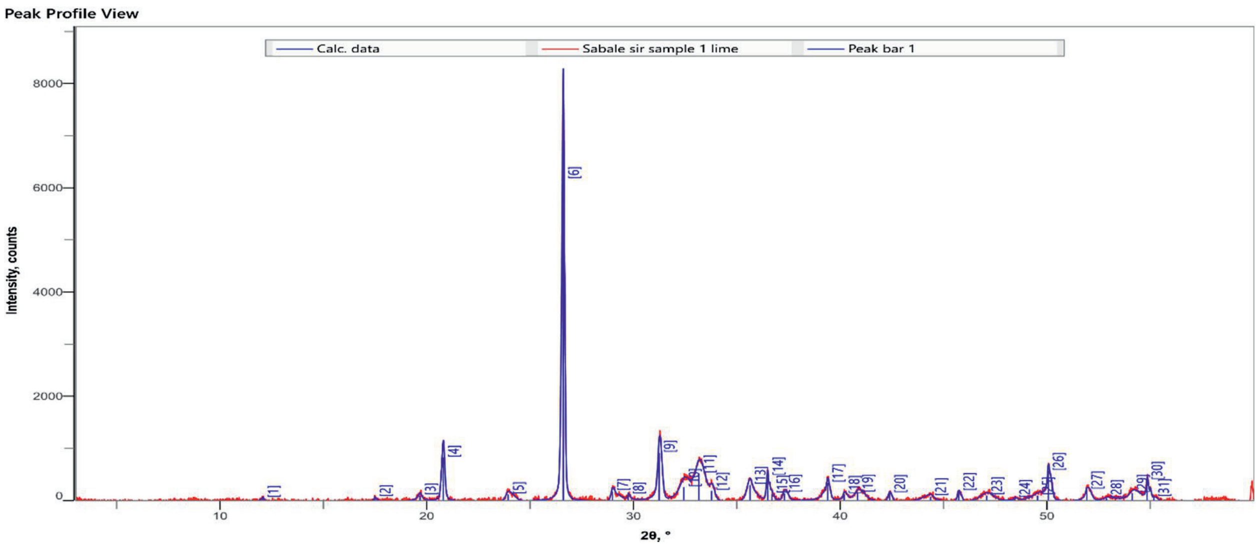


Fig. 27: Shows the XRD peak profile view of lime sample-1.

Peak evaluation conditions

Table 9: Shows the peak evaluation condition of lime sample-1.

Peak search method	*Second derivative method*	*σ cut*		*3.00*			
Profile fitting	Run completed	Peak shape		Split pseudo-Voigt		Fitting condition	Auto(Refine background)

Qualitative Analysis Results

Table 10: Shows the qualitative analysis result of lime sample-1.

Phase name	*Chemical formula*	*FOM*	*Phase reg. detail*	*Space Group*	*DB Card Number*
Si O2	O2 Si	0.719	S/M:COD	152 : P3121	1526860
Fe2 O3	Fe2 O3	1.031	S/M:COD	167 : R-3c:H	1546383
aragonite	Ca (C O3)	2.025	Import:COD	2 : P-1	2103119

2 θ, °

Lattice parameters

Table 11: Shows lattice parameters of lime sample-1

Phase name	a, Å	b, Å	c, Å	α, °	β, °	γ, °
Si O2	4.91706	4.91706	5.40905	90.000	90.000	120.000
Fe2 O3	5.02895	5.02895	13.72715	90.000	90.000	120.000
aragonite	5.86188	5.06748	8.14008	89.999	90.012	89.996

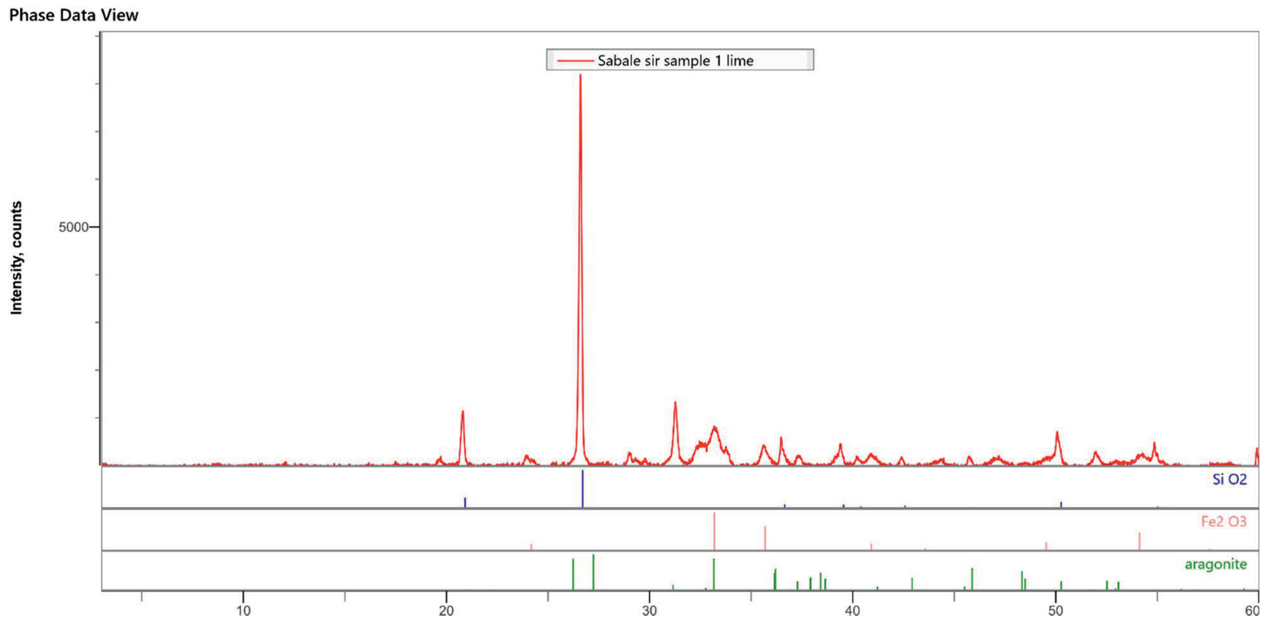


Fig. 28: Shows the phase data view of lime sample-1.

The XRD results show that the lime sample is composed mainly of aragonite, quartz, and hematite. These minerals indicate the use of a traditional lime binder mixed with siliceous and iron-rich impurities, likely derived from locally available raw materials. The presence of aragonite confirms carbonation of lime, while quartz and hematite suggest the addition of sand, clay, or lateritic soil components.

The lattice parameters show that quartz (SiO_2) has equal a and b values with a γ angle of 120°. Hematite (Fe_2O_3) also displays equal a and b values with a γ angle of 120,while aragonite ($CaCO_3$) shows unequal lattice dimensions.

1. Lime sample (XRD analysis): The X-ray diffraction analysis revealed a mineralogical composition dominated by aragonite ($CaCO_3$), quartz (SiO_2), and hematite (Fe_2O_3). The presence of aragonite indicates carbonation of the lime binder and may suggest the use of shell-derived lime, commonly associated with traditional coastal construction practices. Quartz represents siliceous aggregates or natural mineral inclusions, while hematite reflects iron-rich impurities derived from lateritic soils or clay materials.
2. The coexistence of carbonate, siliceous, and ferruginous phases suggests the use of locally sourced raw materials and traditional lime preparation techniques rather than industrially refined lime products.

The XRD analysis revealed the following mineralogical composition: i. Aragonite ($CaCO_3$): Dominant carbonate phase indicating carbonated lime binder; ii. Quartz (SiO_2): Siliceous phase contributing strength and stability; iii. Hematite (Fe_2O_3): Iron oxide phase responsible for ferruginous characteristics and possible reddish coloration.

Curdi lime sample-2-evaluation report

Measurement Conditions

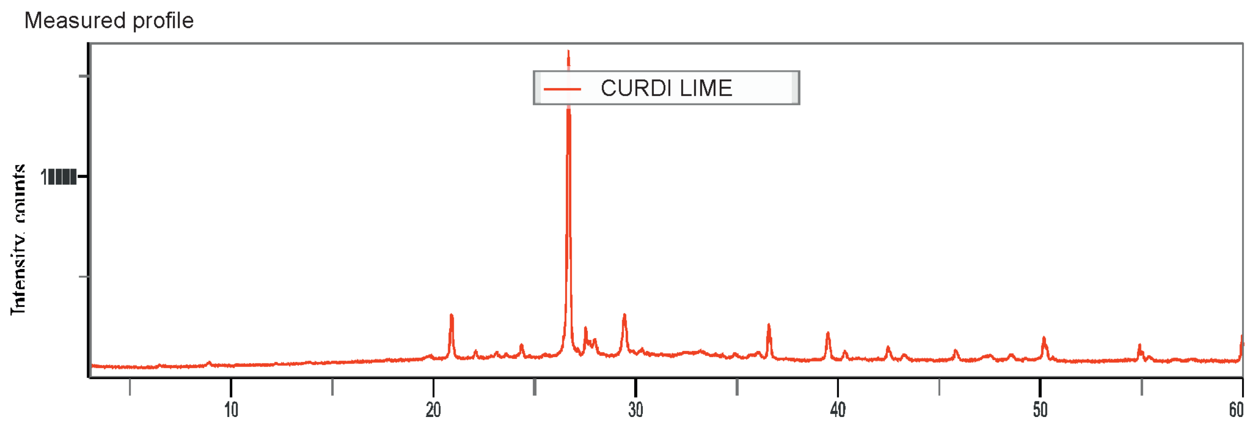


Fig. 29: Shows the measured profile of lime sample-2.

Table 12: Shows the measurement condition of lime sample-2

X-Ray generator	40 kV, 15 mA	Scan mode	1 D(scan)
Incident primary	No unit	Scan speed/Duration time	5.00 °/min
Goniometer	MiniFlex 300/600	Step width	0.01 °
Attachment	Standard sample stage	Scan axis	θ/2θ
Filter	None	Scan range	3 ~ 60 °
Selection slit	None	DS	1.25 deg
Diffracted beam mono	None	IHS	10 mm
Detector	D/teX Ultra2	SS	Open
Optics attribute	None	RS	Open

θ, °

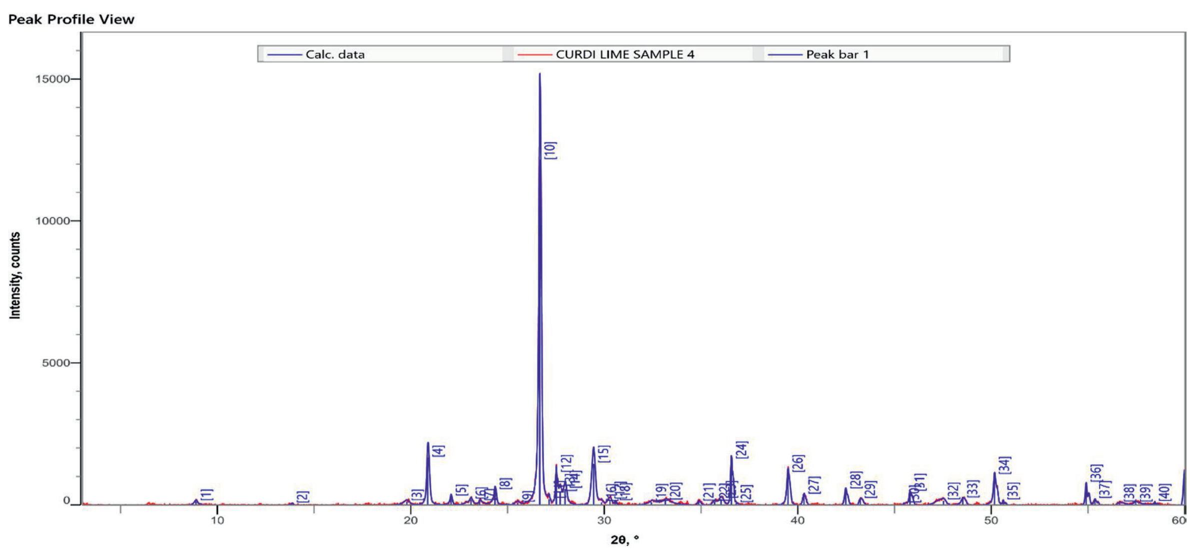


Fig. 30: Shows the peak profile view of lime sample-2.

Peak evaluation conditions

Table 13: Shows the peak evaluation condition of lime sample-2.

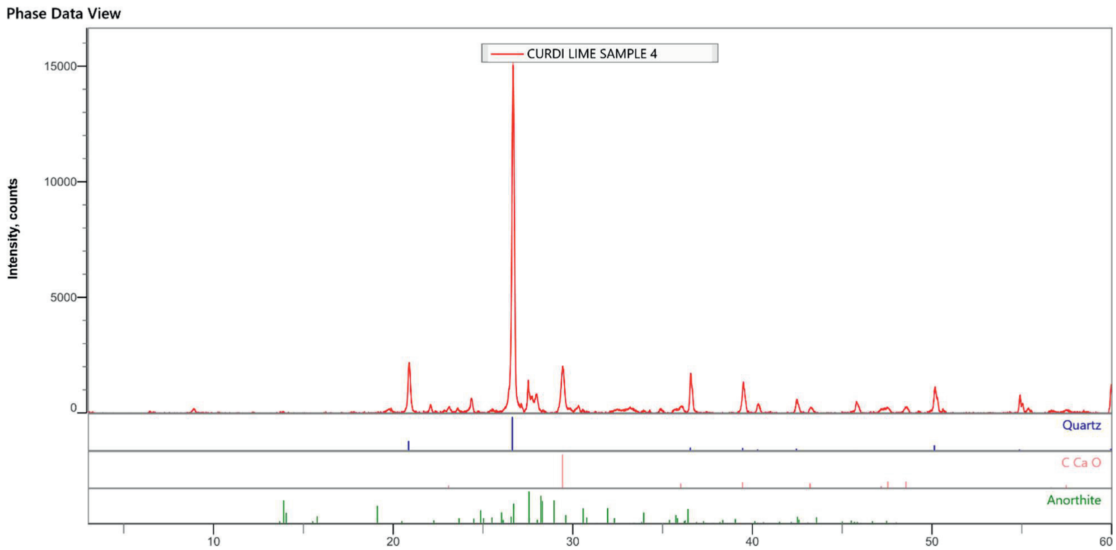
Peak search method	*Second derivative method*	*σ cut*		*3.00*					
Profile fitting	Run completed	Peak shape		Split pseudo-Voigt		Fitting condition			Auto(Refine background)

Qualitative Analysis Results

Table 14: Shows the qualitative analysis result of lime sample-2.

Phase name	*Chemical formula*	*FOM*	*Phase reg. detail*	*Space Group*	*DB Card Number*
Quartz	O2 Si	0.292	S/M:COD	152 : P3121	9009666
C Ca O	C Ca O	0.666	S/M:COD	167 : R-3c:H	1547349
Anorthite	Al Ca O4 Si	1.816	Import:COD	2 : I-1	9001172

2 θ, °



(4) (13) 3,Anorthi 0011 Voigt

Fig. 31: Shows the phase data view of lime sample-2.

Lattice parameters

Table 15: Shows the lattice parameters of lime sample-2.

Phase name	a, Å	b, Å	c, Å	α, °	β, °	γ, °
Quartz	4.91595	4.91595	5.40756	90.000	90.000	120.000
C Ca O	4.98606	4.98606	17.06799	90.000	90.000	120.000
Anorthite	8.10218	12.79887	14.06703	92.790	115.770	91.680

The XRD results show that the Curdi lime sample-2 is composed mainly of quartz, calcium carbonate, and anorthite. These minerals indicate the use of traditional lime material mixed with siliceous and feldspathic impurities, likely derived from locally available soils and aggregates. The presence of calcium carbonate confirms carbonation of the lime binder, while quartz and anorthite suggest the incorporation of sand and clay-rich materials.

The lattice parameters show that quartz has equal a and b values with a γ angle of 120°, Calcium carbonate also displays equal a and b values with a γ angle of 120°, while anorthite shows unequal lattice dimensions with a high β angle (115.77°).

Curdi Lime Sample-2 (XRD analysis): The X-ray diffraction analysis revealed a mineralogical composition dominated by quartz (SiO_2), calcium carbonate ($CaCO_3$), and anorthite ($CaAl_2Si_2O_8$). The calcium carbonate phase indicates carbonation of the lime binder, confirming the use of traditional lime technology. Quartz represents siliceous aggregates or naturally occurring mineral inclusions, while anorthite suggests feldspathic clay or ceramic-related impurities incorporated into the lime matrix.

The coexistence of carbonate, siliceous, and feldspathic phases indicates the use of locally sourced raw materials and non-industrial preparation techniques. The mineral assemblage reflects vernacular construction practices utilizing available lateritic soils, sand, and lime resources.

The XRD analysis revealed the following mineralogical composition: i. Quartz (SiO_2): Dominant siliceous phase contributing strength and durability; ii. Calcium carbonate ($CaCO_3$): Carbonated lime binder phase responsible for hardening; iii. Anorthite ($CaAl_2Si_2O_8$): Feldspathic mineral indicating clay or ceramic-derived inclusions.

Curdi sample-3 lime and mortar-evaluation report

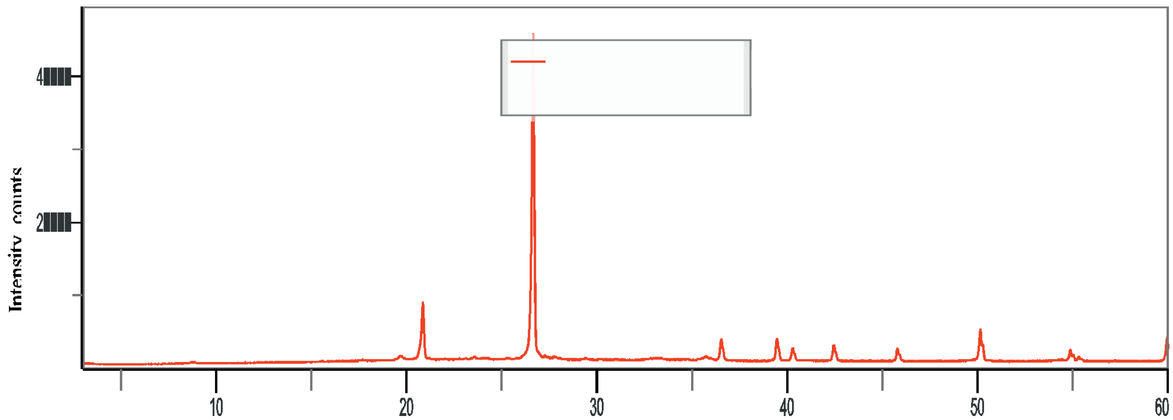


Fig. 32: Shows the measured profile of lime and mortar sample-3.

Measurement Conditions

Table 16: Shows measured conditions of a lime and mortar sample-3.

X-Ray generator	*40 kV, 15 mA*	*Scan mode*	*1 D(scan)*
Incident primary	No unit	Scan speed/Duration time	5.00 °/min
Goniometer	MiniFlex 300/600	Step width	0.01 °
Attachment	Standard sample stage	Scan axis	θ/2θ
Filter	None	Scan range	3 ~ 60 °
Selection slit	None	DS	1.25 deg
Diffracted beam mono	None	IHS	10 mm
Detector	D/teX Ultra2	SS	Open
Optics attribute	None	RS	Open

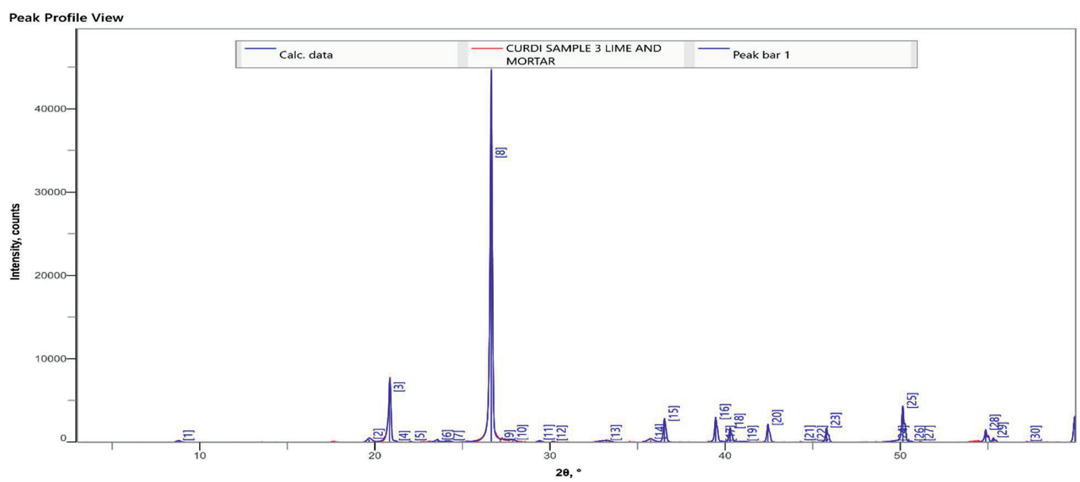


Fig. 33: Shows a peak profile view of lime and mortar sample-3.

Peak evaluation conditions

Table 17: Shows the peak evaluation condition of lime and mortar sample-3.

Peak search method	*Second derivative method*	*σ cut*		*3.00*			
Profile fitting	Run completed	Peak shape		Split pseudo-Voigt	Fitting condition		Auto(Refine background)

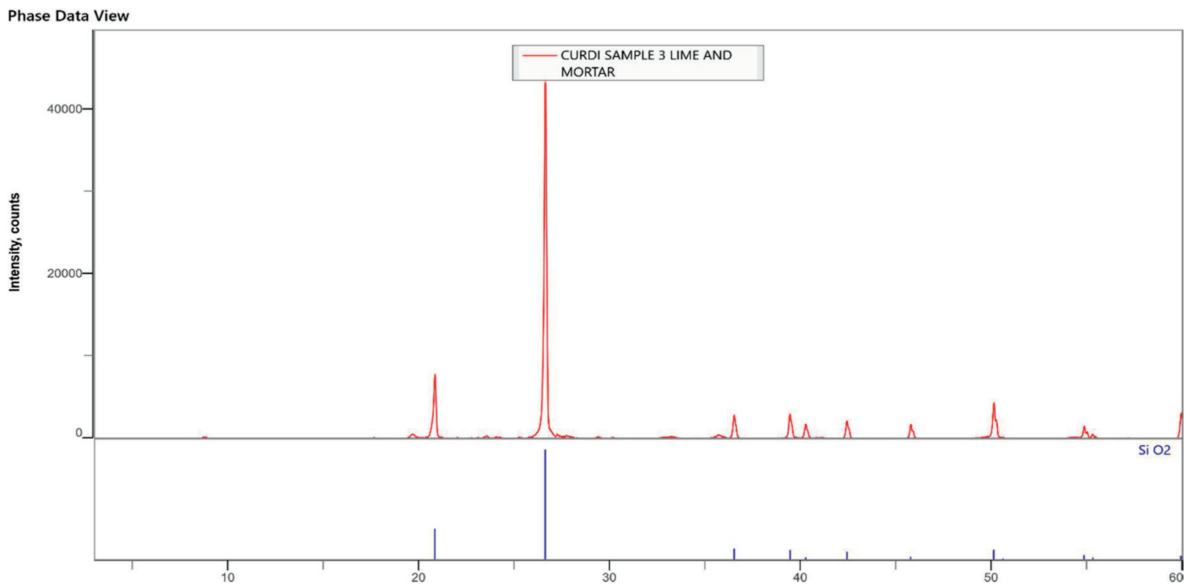


Fig. 34: Shows the phase data view of lime and mortar sample-3.

Qualitative Analysis Results

Table 18: Shows qualitative analysis results of lime and mortar sample-3.

Phase name	*Chemical formula*	*FOM*	*Phase reg. Detail*	*Space Group*	*DB Card Number*
Si O2	O2 Si	0.300	S/M:COD	1 : P1	1536389

Lattice parameters

Table 19: Shows lattice parameters of lime and mortar sample-3.

Phase name	a, Å	b, Å	c, Å	α, °	β, °	γ, °
Si O2	4.91558	4.91658	5.40653	90.000	90.000	120.000

The XRD results show that Curdi sample-3 (lime and mortar) is composed predominantly of quartz (SiO_2). The dominance of quartz indicates the presence of siliceous material, likely derived from sand aggregates or locally available lateritic soils used in the mortar preparation. The absence of significant additional mineral phases may suggest weathering, leaching of lime components, or a silica-rich mortar composition.

The lattice parameters show that quartz has nearly equal a and b values with a γ angle of 120°.

Curdi Sample-3 – Lime and Mortar (XRD analysis): The X-ray diffraction analysis revealed a mineralogical composition dominated by quartz (SiO_2). Quartz represents a stable siliceous phase commonly associated with sand aggregates and naturally occurring mineral inclusions in traditional lime mortars. The predominance of quartz suggests the use of locally sourced sand-rich material in the mortar mix.

The mineralogical simplicity of the sample may indicate prolonged weathering, loss of carbonate phases over time or the preparation of mortar using a high proportion of siliceous aggregates compared to lime binder.

The XRD analysis revealed the following mineralogical composition:i. Quartz (SiO_2): Dominant siliceous phase contributing strength, durability, and structural stability.

Sample-4 mud-evaluation report

Measurement Conditions

Table 20: Shows the measurement condition of mud sample-4.

X-Ray generator	*40 kV, 15 mA*	*Scan mode*	*1 D(scan)*
Incident primary	No unit	Scan speed/Duration time	5.00 °/min
Goniometer	MiniFlex 300/600	Step width	0.01 °
Attachment	Standard sample stage	Scan axis	θ/2θ
Filter	None	Scan range	3 ~ 60 °
Selection slit	None	DS	1.25 deg
Diffracted beam mono	None	IHS	10 mm
Detector	D/teX Ultra2	SS	Open
Optics attribute	None	RS	Open

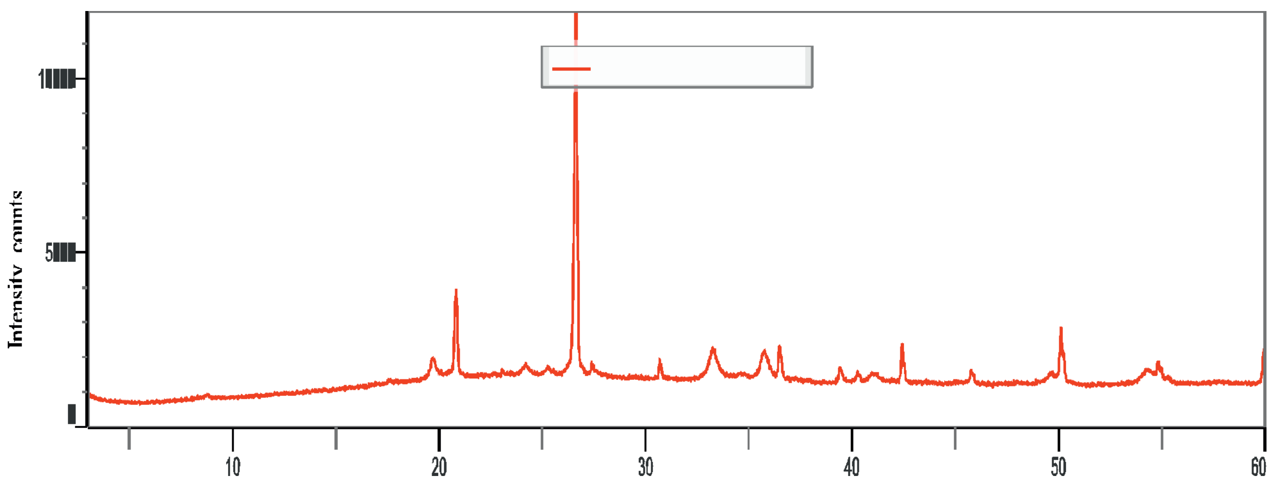


Fig. 35: Shows the measured profile of mud sample-4.

Table 21: Shows peak evaluation conditions of mud sample-4

Peak search method	*Second derivative method*	*σ cut*		*3.00*				
Profile fitting	Run completed	Peak shape		Split pseudo-Voigt		Fitting condition		Auto(Refine background)

Peak evaluation conditions θ, °

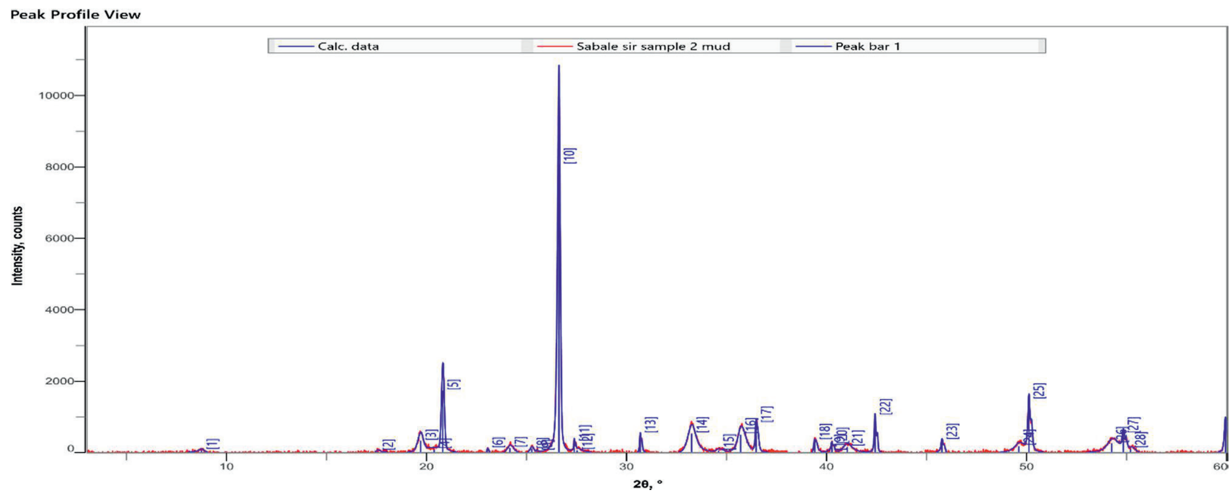


Fig. 36: Shows peak profile view of mud sample-4.

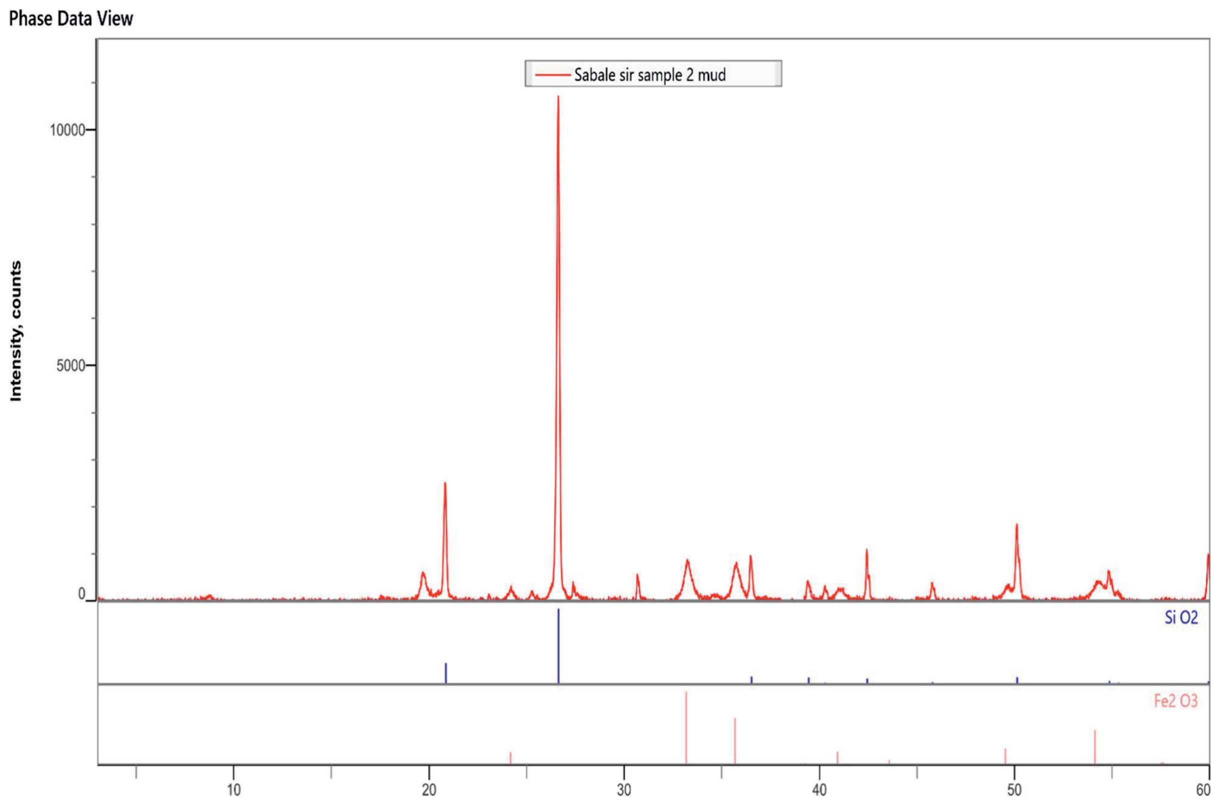


Fig. 37: Shows the phase data view of mud sample-4.

Qualitative Analysis Results

Table 22: Shows the qualitative analysis result of mud sample-4.

Phase name	*Chemical formula*	*FOM*	*Phase reg. detail*	*Space Group*	*DB Card Number*
Si O2	O2 Si	0.453	S/M:COD	1 : P1	1536389
Fe2 O3	Fe2 O3	0.763	S/M:COD	167 : R-3c:H	1546383

2 θ, °

Lattice parameters

Table 23: Shows the lattice parameters of mud sample-4.

Phase name	a, Å	b, Å	c, Å	α, °	β, °	γ, °
Si O2	4.91862	4.91962	5.40988	90.000	90.000	120.000
Fe2 O3	5.02629	5.02629	13.70638	90.000	90.000	120.000

The XRD results show that Sample-4 (mud) is composed mainly of quartz (SiO_2) and hematite (Fe_2O_3). These minerals indicate the use of silica-rich and iron-bearing soil materials, characteristic of lateritic deposits commonly found in the Goa-Konkan region. The presence of quartz suggests sandy siliceous content, while hematite reflects iron oxide concentration responsible for the reddish coloration of the mud.

The lattice parameters show that quartz has nearly equal a and b values with a γ angle of 120°, Hematite also displays equal a and b values with a γ angle of 120°.

Sample-4 – Mud (XRD analysis): The X-ray diffraction analysis revealed a mineralogical composition dominated by quartz (SiO_2) and hematite (Fe_2O_3). Quartz represents the siliceous fraction of the soil, contributing to the structural stability of the mud material, while hematite indicates iron-rich lateritic content derived from local geological formations.

The coexistence of quartz and hematite suggests that the mud was prepared using naturally available lateritic soil mixed with sandy material. This reflects vernacular construction practices utilizing locally sourced earthen resources rather than processed industrial materials.

The XRD analysis revealed the following mineralogical composition: i. Quartz (SiO_2): Dominant siliceous phase providing stability and durability; ii. Hematite (Fe_2O_3): Iron oxide phase responsible for ferruginous characteristics and reddish coloration.

Ceramic analysis

Sample Description: Two sherds were recovered, both refined whiteware, likely part of the same tea plate or cup saucer.

Characteristics

The various characteristics of white glazed pottery are as follows: i) White glossy glaze: Indicates the use of lead or feldspathic glaze, commonly applied to make the pottery non-porous, stain-resistant, and suitable for daily domestic use. Such glazing also enhances durability and gives a finished aesthetic appeal. ii) Smooth surface, high-refinement clay: Suggests well-processed clay with the removal of coarse particles and impurities, which results in a finer texture. iii) One sherd has a green decorative band: This reflects the use of mineral-based pigments (often copper) applied as simple linear decoration, indicating standardized but minimal aesthetic design in mass production. iv) Industrially produced: Implies uniform thickness, standardized shapes, and kiln firing at consistent temperatures, unlike handmade pottery. v)Mid-20th century date range (1940–1985): This period saw widespread mass-produced domestic ceramics in India, often influenced by colonial trade networks and increasing urban consumption patterns. (The terracotta store, 2020)

Cultural interpretation

These ceramics indicate i. a shift from earthenware to industrial porcelain in Goan households; ii.

market access through regional towns; and iii. the changing domestic lifestyles prior to displacement of lime.

DISCUSSION AND CONCLUSION

In the study region the main building stone available is laterite, whose exposures are available throughout the region. Therefore, it is widely available as building stone in the area; it is available in beautiful yellowish-brown to red-dark red and chocolate pleasant colors. Due to the use of lustrous stone in the construction, it became attractive and more spectacular to the heritage structure. Due to the soft nature of this building stone, one can cut into any dimension to the rock as per requirement. Similarly, one can perform any art, architect, drawings, shapes, or idols on this rock. Similarly, it becomes harder to the exposure. Due to the above advantageous characteristics, the locally available laterite in very attractive colour with good properties, which reduces the cost of painting and plastering as well as reduces the heat within the house. By considering all the above advantageous characteristics, the laterite is used here as a building stone for the construction of Someshwar Temple, a heritage structure.

The study of the Someshwar Temple and Curdi settlement shows a mix of traditional and modern building techniques. Mud mortars made from fine laterite soil and organic materials were used in houses, reflecting local construction methods. Lime, with mixed particle sizes, was used in later repairs or additions, showing a shift to more durable materials. Mud houses collapsed quickly under submergence, while lime and laterite-lime buildings lasted longer, showing how material choice affected durability.

The mud bricks were used in construction of a residential structure which is located very close to the Southern vicinity areas of the temple site. A few broken samples which were collected from the constructed wall of the structure were taken for the sedimentological analysis. The sizes and shape-based result clearly indicate that the material for the manufacturing of this brick were collected from the same region. In which the finest number of sediments is a major and which indicates sub angular to sub-rounded shape. This clearly indicates that the soil sediment is formed by moderate rate of transportation.

Since in the construction of Heritage structure lime is used as a binding material. The sources of the lime from the nearby areas of Karnataka such as Bagalkot, Badami etc. A suitable amount of lime samples was studied in the lab to understand the percentage of lime and mortar as well as the nature of soil sediments used in the formation of mortar and sources of lime. The percentage of lime found in the sample was 35% while the percentage of mortar is 65% which clearly indicates that a sufficient amount of lime was used in the construction along with the mortar. The result of shape analysis of the mortar shows that most of the sediment grains belong to sub angular to sub-rounded category.

A large proportion of roof tiles were found at the site because these tiles were use in the roof construction of temple complex and surrounding structures. These styles are high quality material and are manufactured at the local site areas from the local soil. The grains size analysis clearly indicates that the majority of the sediments belongs to fine class about (35%). While due to the majority proportion of clay matter the shape analysis were not possible.

A few pieces of glazed, highly polished ceramic pieces collected from the site. The result of size analysis shows that the majority of the raw material is very fine that is 70%. Hence due to the extreme fine nature of sediment the shape analysis was not carried out.

The roof-tile sample were studied examined under XRD. The result of this analysis shows, i) the tile was manufactured by using **lateritic clay as a raw material which is available in** abundant proportion the area; ii) The firing temperature was likely **600–800°C**, typical of vernacular tile production rather than high-temperature industrial kilns; iii. The reddish coloration and porous texture indicate a **handmade, possibly locally fired tile**, supporting oral traditions that villagers produced their own tiles; iv. Portuguese influence may have standardized tile sizes and forms, but the underlying technology remained rooted in local clay use.

The lime sample No. 1 were analysed under XRD instrument. It shows following observations: i) The lime material was prepared by using carbonate and siliceous resources; ii. The presence of aragonite suggests carbonation under moisture-rich environmental conditions and possible shell-lime origin; iii. Quartz inclusions indicate the addition of sand or naturally occurring silica-rich impurities for improved structural performance; iv. Hematite reflects the influence of lateritic or iron-rich soils commonly found in the Konkan-Goa region, supporting the use of vernacular raw materials and traditional lime technology.

The observations of lime sample-2 were examined XRD machine. It shows important observations, such as i) The lime material was prepared using locally available lime, sand, and clay-rich resources; ii) The presence of calcium carbonate confirms carbonation of the lime binder during the curing process; iii) Quartz inclusions suggest the addition of sand or naturally occurring siliceous impurities for improved mechanical stability; iv) The occurrence of anorthite indicates feldspathic or clay-related materials, possibly introduced through local soils, supporting the use of vernacular construction technology and locally sourced materials in the Curdi settlement.

The lime-mortar sample also examined under XRD, it shows the following observations: i) The mortar material was prepared using locally available silica-rich sand or lateritic soil resources; ii) The dominance of quartz indicates a strong aggregate component within the mortar matrix; iii) The absence of distinct carbonate peaks may suggest weathering, dissolution, or degradation of the original lime binder over time; iv) The material reflects traditional vernacular construction practices utilizing locally available aggregates and lime technology within the Curdi settlement.

The mud sample also observed under XRD and can be interpreted as, i) The mud material was prepared using locally available lateritic and siliceous soil, which is abundantly available in the study region; ii) The dominance of quartz indicates significant sandy and siliceous content within the mud mix; iii) The presence of haematite confirms iron-rich lateritic material, contributing to the reddish coloration and characteristic texture of the sample; iv) The material reflects traditional vernacular earthen construction practices based on the direct use of naturally available local resources in the Curdi settlement.

Finally, the XRD analysis of roof tiles also carried out. It shows i) the raw material of clay containing quartz, feldspar, and mica were available at local sources; ii) The clay fired at moderate temperatures using traditional methods; iii) The tiles were handmade, with Portuguese influence seen in the standard shapes; iv) The recovered ceramic pieces, refined whiteware used for domestic purposes, indicate that people also used industrially made household items alongside traditional materials before the displacement.

Overall, the findings highlight how the people of Curdi adapted to their environment and available natural resources for their betterment. They used locally available materials while incorporating modern and colonial techniques to make buildings stronger. This study helps us to understand the construction methods, daily life, and cultural practices of the community before the village was submerged, providing important information for heritage documentation and conservation.

REFERENCES

Bhomkar, D. (2020). Revisiting the antiquity of Shri Saptakoteshwar in Goa. Heritage: Journal of Multidisciplinary Studies in Archaeology, 8(2), 680–689.

Desai, G. V. (2023). Cultural continuity: Preserving and interpreting cultural heritage through design and planning in Goa. International Journal for Multidisciplinary Research (IJFMR), 5, 1–13.

Desai, G. V. (2025). Archaeology, architecture, and memory: Goa's built heritage in context. International Journal of Innovative Research in Technology (IJIRT), 12(3), 2853–2858.

Directorate of Archives and Archaeology, Government of Goa. (1995). Nave Parva: 400 years of historical archives of Goa, 1595–1995 (Special issue). Government of Goa.

Döndüren, M. S., & Sişik, O. (2017). Materials used in historical buildings, analysis methods and solutions proposals. E3S Web of Conferences, 19, 03019. https://doi.org/10.1051/e3sconf/20171903019

Kathiresan, P., Jayachandran, N., & Kumanan, C. J. (2017). Geospatial technology in quantifying seasonal availability of water stored in Salaulim Reservoir Salauli, Goa State, India. International Journal of Advance Research, Ideas and Innovations in Technology, 3(2). https://www.researchgate.net/publication/316562725

Kaur, et al. (2023). Western Ghats laterite: An architecturally and culturally iconic stone from India with reference to Goa. Geoheritage, 15(1), 1–19.

Lechuga-Crespo, J. L., et al. (2020). A model for evaluating continental chemical weathering from riverine transports of dissolved major elements at a global scale. Global and Planetary Change, 192, 1–14.

Makdur, N., & Narkhede, P. (2018). Study of laterite stone as building material. International Journal of Engineering Research, 7(Special Issue 3), 223–226. https://doi.org/10.17950/ijer/2018/v7/s3/001

Pye, K. (1982). Granular disintegration of gneiss and migmatites. Catena, 12(1), 191–199.

Singh, A. K., Dinesh, D., Singh, G., Jinger, D., Mandal, D., Dogra, P., Kumar, G., Kaushal, R., Roy, T., Islam, S., Desai, S., Mahajan, G. R., Raizada, A., Kumar, P., & Madhu, M. (2023). Soil erosion status, priority treatment areas, conservation measures for different districts of Goa (p. 34). ICAR-Indian Institute of Soil and Water Conservation.

Strain, J. (2025, October 27). X-ray diffraction (XRD) – XRD principle, XRD analysis and applications. Technology Networks. https://www.technologynetworks.com/analysis-separations/articles/x-ray-diffraction-xrd-xrd-principle-xrd-analysis-and-applications-381026

The Terracotta Store. (n.d.). The Terracotta Store | Authentic Indian handmade terracotta clay. Retrieved May 21, 2026, from https://theterracotta.store/