the stone *jaali*

a critical inquiry into
daylight performance

Text & Graphics: Melissa K Smith
Research: Dharmesh Gandhi, Vishal Garg (Guide), Rajan Rawal (Co-Guide)
jaali as an element

The jaali, it is an elegantly chiselled, perforated screen, about as thick as the perforations are tall, which mediates light and wind in architecture throughout India. It is beautiful, sometimes delicate, sometimes strong, playful and traditional. The jaali is well known as a device for wind and light. But how does it actually work? And what about its role in contemporary buildings? Is it useful? This study sets out to explore the daylight performance of the traditional stone jaali through the documentation of 25 mosques in Ahmedabad and a simulation of their critical properties.

of history

The jaali has been widely used in both Islamic and Hindu architecture throughout ancient India. Prominent in temples, mosques and public structures, simple geometric forms characterised these jaalis. The first use of jaalis is found in 6th century Hindu and Jain temples. As early as the 14th century, the first jaali can be found in a mosque, in Cambay. By the 17th, 18th and 19th centuries, concern for refinement in craft spread, particularly in Rajasthan and Gujarat, to domestic architecture.
of cross pollinating craft

Artisan skills tend to cross materials, particularly in times of experimentation. When Islamic rulers conquered kingdoms in western India, they built mosques from the pieces of temples, and also trained local artisans to create elements inline with the requirements of Islam for their mosques. The motif of one religion was thus borrowed and evolved according to a newer one. The geometries of craft can also pass across material. The resemblance between jaali pattern and local textile block patterns is unmistakable, according to some Ahmedabad historians.

of air

Not only used for the mediation of light, the jaali is also a critical tool in modifying air currents for the indoor climate. The small openings in the jaali increase the velocity of the air passing through, so even a mild breeze outside can be felt in the interior of the space it protects. Furthermore, because of the small openings, large gusts of wind, which carry dust, are stopped by the mesh-like structure of the opening.
of light

Finally, its primarily known purpose: light. The jaali filters the intense white light of the high sun through a series of small openings, gathered together to form a screen. The pattern of the screen creates a dappled light in the interior, and reflects light off surfaces in relief to reduce the amount of light coming from a given opening. Not only does it reduce direct beam radiation in a space, but it also cuts down on illuminance (a necessary task in most of India!) and glare, through the ingenious use of a semi regulated system of stone tile carving.

the study: a jaali's daylight performance

This study looks at the stone jaali’s daylight performance, through the documentation of a series of mosques in Ahmedabad. The initial analysis develops the criteria for a range of solid void ratios present in the carved elements, and a second stage of analysis uses that average to construct a digital model and simulate the jaali’s illuminance and luminance levels. For a jaali, the two criteria by which its performance is determined are the relationship between solid and void in its surface, and its thickness.
solid void relationship

The relationship between carved and uncarved, with implications from both the technique of the craft and the intended performance of the screen, reflects in the architectural character of the resulting façade. The limitations of carved sandstone have as much to do with the presence of solid as both the need for, and protection from, light. This relationship was measured by analysing the area of the elevation of the jaali. For facades in all cardinal directions, the solid is typically between 40% and 60%, and void between 60% and 40%.

overhang ratio

The maximum depth of any individual opening in the jaali over the thickness of the stone is the overhang ratio. In all cases, this falls between 0.8 and 1.2, which means that any opening is roughly as deep as it is tall. There are no remarkable differences between jaalis oriented differently, most likely because the jaali is effective for the most extreme scenario, and then repeated on all facades.

In a scenario where pieces are essentially prefabricated and used in a system (or pre-crafted), the efficiency of a single repeatable solution is valuable. Also because indirect light is a major factor in this region, provided that direct beam radiation is taken care of, the overall illumination level is a critical criterion.
overhang depth assessment

area = 26383 sqmm (voids) 80%  
area = 17717 sqmm (solids) 40%

area = 31467 sqmm (voids) 71%  
area = 12833 sqmm (solids) 29%

area = 36606 sqmm (voids) 60%  
area = 17494 sqmm (solids) 40%

area = 17096 sqmm (voids) 39%  
area = 27004 sqmm (solids) 61%

area = 22185 sqmm (voids) 50%  
area = 21915 sqmm (solids) 50%

area = 16750 sqmm (voids) 36%  
area = 27310 sqmm (solids) 62%

area = 19252 sqmm (voids) 43%  
area = 24848 sqmm (solids) 57%

area = 16911 sqmm (voids) 38%  
area = 27189 sqmm (solids) 62%

area = 26534 sqmm (voids) 60%  
area = 17866 sqmm (solids) 40%

area = 21878 sqmm (voids) 50%  
area = 22222 sqmm (solids) 50%

area = 20002 sqmm (voids) 46%  
area = 24086 sqmm (solids) 54%

solid void assessment
**Frame Size:** 250mm x 250mm

**Panel Size:** 0.9m x 1.2m

**Sill Height:** 0.9m

**Window to Wall Ratio:** 2 (20% opening)

**Stone thicknesses:** 40mm, 50mm, 60mm

**Solid Void Ratios:** 67% (40% solid, 60% void), 1.5 (50% solid and void), 1.1 (60% solid, 40% void)

**Overhang Ratio:** 0.8 (40mm thick), 1.0 (50mm thick), 1.2 (60mm thick)

---

**Simulated Model**

Twenty-five mosques were documented. By averaging the many types of jaalis, a model for simulation was derived.

The simulation was done in Radiance, with a model built in Ecotect. Radiance is one of the most advanced simulation engines for daylight and lighting. In the simulation, the derived jaali is placed in a 3x3x3m room and tested at 9am, 12pm and 3pm on March 21, June 21 and December 21. All this was done to evaluate the simulated jaali with metrics of illuminance, uniformity ratio, and glare.

**Illuminance** measures, here in lux, the amount of light falling on a surface.

**Uniformity ratio** describes the uniformity the luminance (or light reflected from a surface) on a working plane.

**Glare** occurs when the difference in brightness between two neighboring surfaces is too high, which affects the eye's ability to adjust for brightness. It is what causes people to see spots. Brightness ratios of 1:3 are acceptable on a work surface, 1:10 in the immediate cone of vision, and 1:40 in a room.
Case 1
40mm thickness - 0.8 ratio >> ht. of void 32mm

<table>
<thead>
<tr>
<th>50mm × 28 x 30m</th>
<th>s/v ratio 50% (equal division) 31250 sqmm</th>
</tr>
</thead>
<tbody>
<tr>
<td>solid ratio 60% - 25000 sqmm</td>
<td></td>
</tr>
<tr>
<td>void ratio 40% - 25000 sqmm</td>
<td></td>
</tr>
</tbody>
</table>

Case 2
40mm thickness - 1 ratio >> ht. of void 48mm

<table>
<thead>
<tr>
<th>40mm × 24 x 30m</th>
<th>s/v ratio 50% (equal division) 31250 sqmm</th>
</tr>
</thead>
<tbody>
<tr>
<td>solid ratio 40% - 25000 sqmm</td>
<td></td>
</tr>
<tr>
<td>void ratio 60% - 37500 sqmm</td>
<td></td>
</tr>
</tbody>
</table>

Case 3
40mm thickness - 1.2 ratio >> ht. of void 48mm

<table>
<thead>
<tr>
<th>40mm × 26 x 30m</th>
<th>s/v ratio 50% (equal division) 31250 sqmm</th>
</tr>
</thead>
<tbody>
<tr>
<td>solid ratio 40% - 25000 sqmm</td>
<td></td>
</tr>
<tr>
<td>void ratio 60% - 37500 sqmm</td>
<td></td>
</tr>
</tbody>
</table>

Case 1
50mm thickness - 0.8 ratio >> ht. of void 40mm

<table>
<thead>
<tr>
<th>40mm × 23 x 30m</th>
<th>s/v ratio 50% (equal division) 31250 sqmm</th>
</tr>
</thead>
<tbody>
<tr>
<td>solid ratio 40% - 25000 sqmm</td>
<td></td>
</tr>
<tr>
<td>void ratio 60% - 37500 sqmm</td>
<td></td>
</tr>
</tbody>
</table>

Case 2
50mm thickness - 1 ratio >> ht. of void 50mm

<table>
<thead>
<tr>
<th>50mm × 22 x 30m</th>
<th>s/v ratio 50% (equal division) 31250 sqmm</th>
</tr>
</thead>
<tbody>
<tr>
<td>solid ratio 40% - 26000 sqmm</td>
<td></td>
</tr>
<tr>
<td>void ratio 60% - 37500 sqmm</td>
<td></td>
</tr>
</tbody>
</table>

Case 3
50mm thickness - 1.2 ratio >> ht. of void 60mm

<table>
<thead>
<tr>
<th>60mm × 27 x 30m</th>
<th>s/v ratio 50% (equal division) 31250 sqmm</th>
</tr>
</thead>
<tbody>
<tr>
<td>solid ratio 40% - 25000 sqmm</td>
<td></td>
</tr>
<tr>
<td>void ratio 60% - 37500 sqmm</td>
<td></td>
</tr>
</tbody>
</table>

Case 1
60mm thickness - 0.8 ratio >> ht. of void 48mm

<table>
<thead>
<tr>
<th>60mm × 21 x 30m</th>
<th>s/v ratio 50% (equal division) 31250 sqmm</th>
</tr>
</thead>
<tbody>
<tr>
<td>solid ratio 40% - 25000 sqmm</td>
<td></td>
</tr>
<tr>
<td>void ratio 60% - 37500 sqmm</td>
<td></td>
</tr>
</tbody>
</table>

Case 2
60mm thickness - 1 ratio >> ht. of void 60mm

<table>
<thead>
<tr>
<th>60mm × 24 x 30m</th>
<th>s/v ratio 50% (equal division) 31250 sqmm</th>
</tr>
</thead>
<tbody>
<tr>
<td>solid ratio 40% - 26000 sqmm</td>
<td></td>
</tr>
<tr>
<td>void ratio 60% - 37500 sqmm</td>
<td></td>
</tr>
</tbody>
</table>

Case 3
60mm thickness - 1.2 ratio >> ht. of void 72mm

<table>
<thead>
<tr>
<th>72mm × 28 x 30m</th>
<th>s/v ratio 50% (equal division) 31250 sqmm</th>
</tr>
</thead>
<tbody>
<tr>
<td>solid ratio 40% - 25000 sqmm</td>
<td></td>
</tr>
<tr>
<td>void ratio 60% - 37500 sqmm</td>
<td></td>
</tr>
</tbody>
</table>

↑ tile combinations for analysis

↑ workplane level for light readings, window overhang diagram

Indian Architect & Builder - December 2014
beautiful findings

The thickness makes all the difference.

The highest levels of both illuminance and glare occur with a solid-void ratio of 0.67 (40% solid, 60% void) and an overhang ratio of 0.8. An increase in the solid-void ratio at a particular thickness creates a more uniform distribution and reduces glare, but also reduces illuminance. An increase in thickness also reduces illuminance and glare.

Finally, according to this study, which assumed a program of office use for the standard contemporary building, a solid-void ratio of 1.5 (60% solid, 40% void) and an overhang ratio of 1.2 (60mm thickness) produces the most uniform distribution with least glare and best illumination levels ranging from 100lx to 800lx, with the majority of the levels between 200lx and 600lx; appropriate levels for typical office work.

These jaalis in fact act as a delicate light modifier, the carving in each tile operating as a group of deep, protected windows. Paneled across the opening, they work in series at the scale of an ant, filtering the sunlight. In its focus on purely the solid void ratio, the study misses the nuances of the role of pattern in the jaali. In reality, the harshness of the simulated approximation is reduced further by the relief of the carved surfaces, which through the decay of reflected light reduce the contrast between bright outside and darker interior.
why it matters

Could buildings work better now if we thought about jaalis as they once were…with thickness and an overhang ratio around 1? In its translation in contemporary design, this perforated screen has often been flattened into a perforated sheet. This sheet does block some direct beam radiation. But it completely misses the power of the thick jaali, the one whose depth operates as an extending chhajja wrapping each opening, and whose thickness also absorbs some of the heat of the sun, working to keep the thermal lag in action and reduce the building’s peak temperatures. Buildings today could immensely benefit from a jaali conceived as it previously performed; one whose thickness was tuned to cut the sun for a measured illuminance, and whose material also worked toward maintaining the cool inside.

Melissa Smith is an architect and city planner at banduksmithstudio, an architecture, urban design and research practice in Ahmedabad. Her work navigates architecture and the city, dealing with issues of material, energy and change in the built environment and its inhabitants. She also teaches at CEPT University, consults for CARBSE, and writes and draws about the state of architecture and planning in India.

Dharmesh Gandhi is a graduate of the CEPT University, Faculty of Design, Master of Interior Architecture Design Program (MIAD). The research for this work was carried out as a part of the Master’s Thesis for MIAD, CEPT University.

Vishal Garg is Professor at International Institute of Information Technology at Hyderabad and heads the Center for Building Science at IIITH who works in across areas of building performance, from smart sensor occupancy to fuzzy logic air conditioning and intelligent building. He has contributed to national level building code formation, and is engaged in field and lab experiments for cool roofs, daylighting and artificial lighting, as well as building controls.

Rajan Rawal is a faculty member of CEPT University. His work area includes energy and habitat, building energy policies and technologies. He is also Director of the Centre for Advanced Research in Building Science and Energy at CEPT University which is leading the US-India Clean Energy Project on Building Energy Efficiency.