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ON THE SUSTAINABILITY OF THE ANCIENT RATNAGIRI UNIVERSITY COMPLEX: A DESIGN RECONSTRUCTION STUDY

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ABSTRACT

Ratnagiri University was an ancient residential Buddhist University that flourished during the period of 6th-12th century CE in Orissa (20.6330N 86.3330E). In this study we seek to examine the energy efficiency of the University's edifices from a fluid mechanical point of view, using the Software Autodesk® Ecotect® and X-Flow. From a site visit, notable phenomena such as stack ventilation effects in the multi storied dormitories and acoustic filtering of high frequency sounds were suggested upon examining the building forms, which included stupas, courtyards, both windowless and windowed rooms and numerous sculptures amongst a large medley of archaeological remains. This study, the first ever to analyze an ancient Buddhist University, places a particular emphasis on the orientation, siting, infiltration, ventilation, day lighting and acoustics. From these analyses we seek to infer the prowess of the populace of that period, concerning harness of natural resources and design strategies.

Keywords: design reconstruction, heat transfer.

BUDDHIST ARCHITECTURE IN RATNAGIRI

From about the 5th century CE brick built Buddhist religious structures became common and was particularly evident in the Ratnagiri complex (Figure-1). These include Buddhist Chaitya halls, monasteries and stupas. Bricks were easy to procure in the plains, whereas stone was not always readily available. And bricks also afforded the advantage of convenient handling and flexibility in construction technique because of their small size [1]. One difficulty encountered was the bridging of spaces as in the case of doorways, windows, and other openings. The craftsmen attempted to overcome this struggle by using exceptionally large bricks, some early examples being more than 50 cm long. Later on they resorted to lintels of wood and stone, as can be seen in the remains of Ratnagiri.

Figure-1. Aerial view of the Ratnagiri monastery.

Figure-2. Sculptural detail on the monastery wall.

On all four sides of the quadrangular monastery, there were innumerable sculptures lined up against the walls of the monk cells (Figure-2). One is led into the quadrangle through a stunningly beautiful jade gate (Figure-3). Though now in ruins, there was sufficient evidence to suggest that this monastery was once double storeyed, with the upper floor being supported by the now broken pillars extending through the perimeter of the courtyard.

On the left of this monastery was another smaller one. Believed to be built at least three decades later, it was a much smaller structure and single storeyed (Figure-1). A study of this domicile tends to reveal the true extent of Buddhist architecture and how it widened the view of extant features. Some notable instances were the presence of anterooms and introduction of arch windows, which seemed to be concentrating all the noble thoughts as the monks sat under them in the light.

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Figure-3. The famed Jade gate in Ratnagiri.

RECONSTRUCTING THE PAST: DESIGN AND MODELLING STUDIES

In the ancient times, people were not exposed to detailed studies of fluid dynamics and heat and mass transfer as we are now. Yet, their architectural prowess was commendable. They understood the climatic conditions and the temperature variations, and had suitably developed their buildings with the easily accessible natural resources. This study deals with the analysis of the Buddhist monastery at Ratnagiri in a fluid-dynamic and thermodynamic angle. We have performed analyses and discussed the corresponding results on the major wind directions around the year, solar irradiance, acoustics in the internal spaces, orientation of the monastery, and ventilation systems. The aim of the study is to ascertain the level of energy efficiency of the monastery that had been built in the 3rd century CE. Using Software Solidworks [2], a 3D CAD model of monasteries 1 and 2 were fabricated using dimensions obtained from Google Earth images and various other sources [3, 4, 5], to serve as a model for wind flow simulations and construction of a subsequent model in Autodesk Ecotect (see Figure-4).

In order to be able to better analyze and understand the complex processes taking place in Ratnagiri University a few assumptions need to be made. Firstly, the local climate should be considered as the one known variable that plays a major role in the orientation, selection of building material, lifestyle of the monks, etc. Keeping this in mind we proceeded to perform a detailed day-lighting and thermal analysis; along with a comparison of the orientation of the University to the best orientation for a building in Ratnagiri. In order to help us better visualize these processes and attain the results, we have used the software Autodesk Ecotect Analysis [6] (see Figure-4).

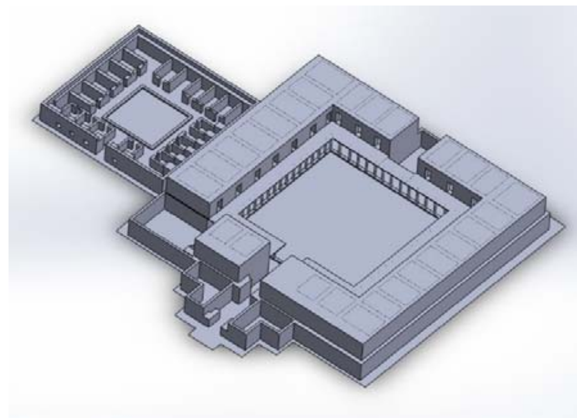

Figure-4. 3D CAD model of monasteries 1 and 2 used for wind flow simulations.

Since Ratnagiri doesn't have a Weather data file of its own we have used the Weather data file for Bhubaneshwar. An analysis of the Weather data file for Bhubaneshwar reveals that there is a predominance of hot, humid days throughout the year. The summer temperature can go as high as 45^{o}C, while in winter it falls to temperatures like 13^{o}C. The prevailing wind directions are mainly Westerly and South- Westerly (see Figure-5).

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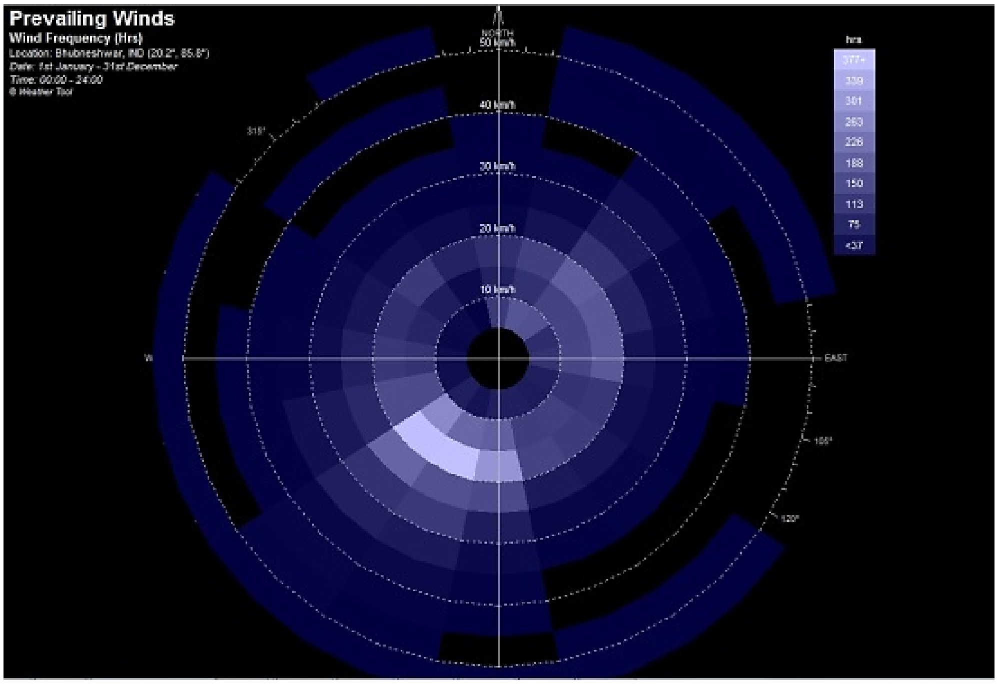

Figure-5. A yearly wind rose showing a predominant south-westerly flow (Bhubaneshwar, India).

EFFECT OF ORIENTATION

Orientation plays a major role in the indoor comfort levels. A building needs to absorb more amount of incident heat in winter while it needs to reflect back a fraction of the same in summer, in order to be able to attain a proper working temperature inside the room, thereby making it more comfortable for the Buddhist monks. Autodesk Ecotect provides us an optimum orientation, based on average daily incident radiation on vertical surface. In the case of Bhubaneshwar, if a rectangular room is oriented in an East-West direction lengthwise then it has the most optimum orientation (Figure-6). This orientation is based on the latitude and longitude of the region and will slightly differ for buildings at different altitudes.

In both the monasteries, most of the rooms are oriented in the East-West direction, making them optimum for living. The rooms were clustered on all four sides of the monastery and opened into the courtyard. The rooms were rectangular and walls were common between two coincident rooms. The sharing of common walls is an element used even in present day sustainable architecture designs.

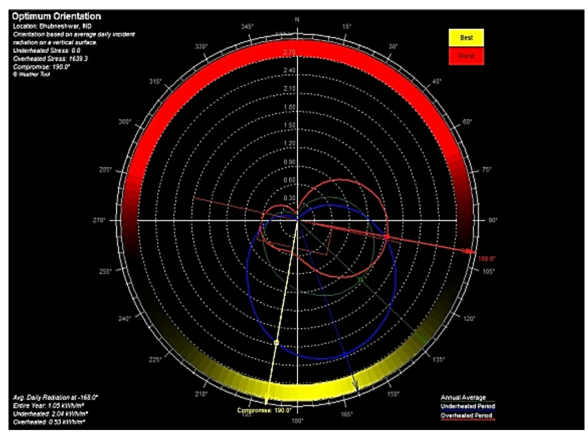

Figure-6. An image showing the best case scenario for Bhubaneshwar.

DAYLIGHT ANALYSIS

We will now be discussing the daylight analysis that has been performed for ground and first floors of the monasteries. The rooms had voids for doors, which made for large active zones. These resulted in high solar gain throughout the year, and mainly in summer (Figures 7(a) and 7(b)).

The Figures we obtained reveal the extent of day lighting, which is the practice of placing windows or

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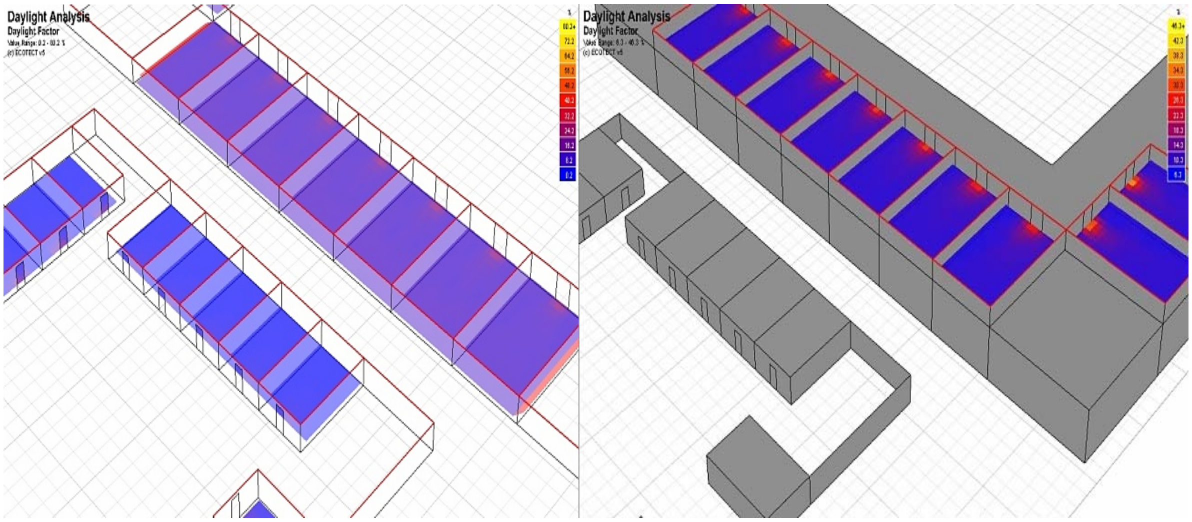

Figure-7(a)-(b). Daylight analysis of ground and first floor of monasteries 1 and 2. The absence of doors and windows results in high Daylight Factors in corresponding areas marked in Orange and Red.

other openings and reflective surfaces such that during the day natural light provides effective internal lighting. It can be calculated using a Daylight Factor, which compares interior light levels to exterior light levels. On comparison with other standard Daylight factors we can conclude that the rooms were all quite effectively lit up during the day.

ACOUSTICS ANALYSIS

The acoustic performance of a building is primarily determined by estimating the internal reverberation time. Reverberation time (RT60) is defined as the time required, in seconds, for the average sound in a room to decrease by 60 decibels after a source stops generating sound. It is affected by various factors:

- Materials used
- Building shape and dimensions
- Presence of reflectors and insulators

The optimum reverberation time of a room depends on its intended use. A concert hall should in an ideal world have a reverberation time of around 3s, for a rich and full sound, with discernible bass. The Notredame, with a reverberation time of 8.5s is ideally suited for resonant wind instruments, which would sound fuller due to reverberation, but is not suited for string instruments, where the repeated echoes will mask the sound produced by each successive string, and it is most definitely not suited to speech, as again, the repetitions will make any uttered words inaudible. The values of reverberation time for different settings are tabulated in Table-1 and the RT60 values of some iconic structures are given in Table-2.

Table-1. Values of reverberation time for different settings.

Primary use of hall	Reverberation time
Speeches and lectures	1s - 1.5s
Music	1.5s-2.5s
Residencies	0s-1s
Open air	0s

Table-2. RT60 values of some iconic structures.

Name	Reverberation time
Sydney opera house	2.2s
French Notre Dam	5.5s
Lecture hall	6s

Application to Ratnagiri Monastery 1: The ecotect acoustic analysis tool was used to determine the reverberation and time inside monastery 1.

The calculations were carried out for an imaginary source: a column speaker generating a 60Db sound at a frequency of 500Hz.The source was placed in front of the sanctum, at a height of 1.5m, to simulate conditions where a senior monk would address his students.

Table-3. Audio frequencies for the courtyard when 70% occupied.

FREQ.	ABSPT.	RT(60) total
-------	-------	-------
63Hz:	11.661	0.77
125Hz:	8.746	0.91
250Hz:	6.802	0.93
500Hz:	0.972	1.38
1kHz:	0.972	0.87
2kHz:	0.972	0.52
4kHz:	1.944	0.34
8kHz:	.972	0.15
16Khz	1.944	0.17

From the curve obtained (Figure-8, Table-3), it can be concluded that sound in the frequency range of 400Hz to 1 KHz would have been crisp and lively. This frequency range corresponds to that of a group of monks chanting, which suggests that any chanting would have filled the monastery with a powerful, resonant sound.
Further, for the human voice frequencies (100Hz-400Hz) RT60 was about 1s, which makes the interior of the monastery particularly suited to speeches and songs.

On the other hand, instruments, other than low frequency percussion, would have sounded flat in these settings.

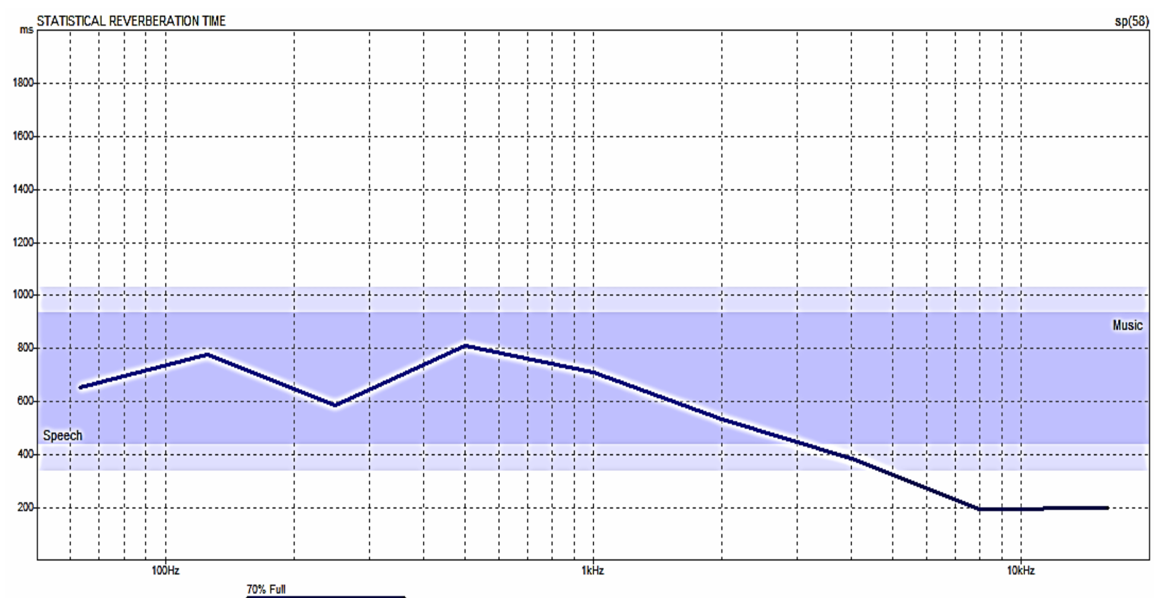

Figure-8. Rt60 for a 70% occupied courtyard.

X-FLOW SIMULATION

To enable us to perform a computational fluid dynamical analysis on the two monasteries, we used the software XFlow CFD [7]. It helped in simulating the wind flow patterns in and around the monasteries at the required average speeds and directions (as determined from the wind rose diagram in Figure-5). To reiterate, the two prominent wind directions through the course of the year were determined to be southwest, during summer, and northeast, during winter.

For the first simulation, the model was oriented so as to receive wind flow from the south-western direction (Figure-9). The winds were shown to separate at the south-west edge of the monasteries, smoothly flowing around the outside walls. A small section of the wind also blew over the wall and into the courtyard below, due to the lower pressures at that area, and subsequently into the northern and eastern cells. For the second simulation the wind came from the opposite direction, northeast (Figure-10). As can be expected, there was a reversal in the pressure levels of all the cells, and subsequent ventilation. Winds at fairly steady speeds swept into the southern and western cells, while those at the northern and eastern received less. These results indicate clearly that, in terms of ventilation, summers at the monasteries were more comfortable for the monks living in the north-eastern side, while it was a reversal of fortunes during the winter. An important point to note was that the northeastern winds were relatively slower but the dissipation per unit area was more. This indicates that low speed winds help in better ventilation when the edifices have a closed architectural design [8, 9].

On experimentation with various wind directions, it was discovered that if the wind flows in the northern direction, then the number of cells that experienced sufficient ventilation reached maximum - all cells except those facing north. In such a situation the wind enters the monastery uniformly through the main entrance and spreads throughout complex.

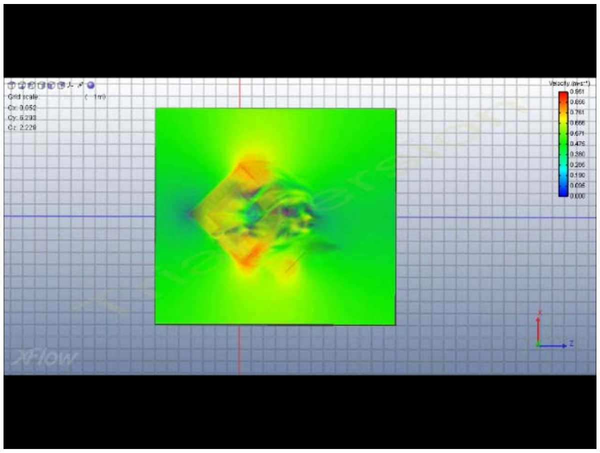

Figure-9. South-Westerly flow into the monastery.

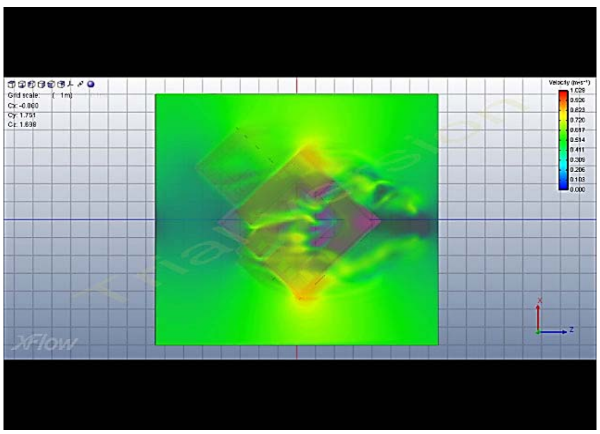

Figure-10. North-Easterly flow into the monastery.

ENERGY REQUIREMENTS

In that time, the energy requirements were basically for cooking and lighting purposes. Shelves were built in the living quarters where monks kept oil lamps to fulfil their basic requirements of reading and traversing in the room. Oil torches, bonfires, diyas could have been used for lighting purposes. Burning wood, forest litter, animal excreta could be used to produce heat in winters or to cook food.

Energy requirements were mostly basic as monastic life demanded. The motive behind the mention is their impact on the thermal, ventilation and lighting conditions in the living quarters of the monks.

RESULTS AND CONCLUSIONS

a) As we have seen from the Ecotect Analysis, the solar orientation of the monastery was near-perfect. It calls for speculation over whether the monks had intentionally built the edifices while observing the movements of the sun, or it was simply a coincidence. However this orientation could not help completely in matters of lighting and ventilation through pressure differences, due to various drawbacks like the absence of windows in monastery 1.

b) Presence of soffits over the ground floor rooms further hindered lighting conditions and made activities like reading difficult in the lower level cells. However, the 1st floor cells would have faced no such problems, and lighting would have been sufficient.

c) Acoustic features of the monasteries were determined to be ideal for human speech. This is important evidence towards the notion that scholars would have learnt a majority of their lessons in the courtyard. To a greater degree, the study also revealed that any instrument with a high frequency would have had a flat tone, thus strengthening the notion that the monasteries were places of solitude intended for enlightenment and the silent worship of Lord Buddha.

d) Computational fluid dynamic simulations demonstrated the wind flow patterns in the monasteries during both summer and winter. Neither situation was satisfactory, as half the rooms of the 1st floor always received insufficient wind flow.

e) Thus, taking factors of solar orientation, temperature, and wind flow into account, the monks would have had to mainly depend on the pressure differences created by the sun's heat for a uniform air flow. Winds tended to circulate mainly at a single inside corner of the monasteries.

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