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Search for the Most Climate Responsive Shape for Stacked Buildings in Warm-Humid Climate

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1. INTERLOCUTION

The introduction of computational techniques and computer aided modelling helped in making a paradigm shift in architecture. Modern construction technologies and methods also aided this evolution. Architecture has become streamlined, with prefabricated modular components being used in-situ construction. The building sector accounts for nearly 40% of total energy consumption. In an era, where excess energy consumption is being considered a taboo, energy optimised building form, geometry, and shape-grammar are being considered increasingly important. In this current paper, efforts are being made to achieve sustainable and low energy buildings through form optimisation, in the urban context of Kolkata. Several generic stacked residential and commercial building forms are analysed based on the insolation and surface area (for ventilation) to find the most optimum orientation and proportions. A conclusion about the functional use of optimum form has also been discussed. The further scope of this paper could explore the dynamics of building skin to create functional climate responsive units.

2. STUDY OBJECTIVE

The primary objective of this study is the search for the most optimised form for the warm and humid climate (Kolkata is taken as the region). The basic factors for optimisation are taken as overhead insolation, western insolation and surface perimeter for prevailing wind direction. Various general building shapes, which account for most building forms and geometry, have been optimised based on the above mentioned factors. A general conclusion, about the best possible proportion and orientation for buildings in a specific climate mostly satisfies the scope of this study.

3. PROCEDURE

The maximum heat gain occurs due to insolation through the walls and roof of the building. To reduce the insolation, the surface to volume ratio of any building form must be less. On the other hand, to counter the high humidity, natural ventilation is essential. Natural ventilation can be increased through increase of surface area of the building, which in turn signifies high surface to volume or its two dimensional counterpart – **Perimeter to area ratio.** As the study has been done for stacked buildings with similar floor plans, height becomes a constant factor and can be eliminated from the list of parameters.

The entire process of optimization has been done based on a few climatic parameters which characterize the warm-humid climate of Kolkata. The solar radiation or insolation that occurs during summer have been compartmentalized into eastern-overhead insolation and western insolation. The maximum heat gain occurs through the overhead insolation which cannot be minimised by form or orientation optimization, if the floor area remains constant. On the other hand the western and eastern glare can be minimised by the optimum orientation and/or the optimum form. Again, in the warm-humid climate of Calcutta, natural ventilation and air-changes-per hour is a vital factor for human comfort. So, to increase natural ventilation, the built forms need to have a higher perimeter to area ratio (as mentioned earlier) which in turn would increase insolation as higher surface area increases the amount of radiation received. Thus insolation and ventilation become two competing factors for the evolution of the most optimised form and orientation. So to optimise keeping all the above factors in mind, a fitness function must be generated which would act as the function for evolutionary solver—GALAPAGOS, in the rhino-grasshopper platform.

The fitness function is based on the priorities of competing variables. The ratio of the variables portray their importance in the solver. To get optimum solution, the ratios should preferably be not too large or small. The fitness function for this solver:

$F = 0.4x + 0.3y - 0.3z$, where

X: the difference between western summer and winter insolation (kWh/m^2 day)

Y: the difference between overhead-eastern summer and winter insolation (kWh/m^2 day)

Z: the intersection between wind rose mesh during summer months and building geometry (m)

Nine standard building shapes were considered. The parameters for optimization includes:

The dimensions (dimension of each façade has been considered and a small range has been assigned to it)

Orientation

Scale (scale in x and y axes has been assigned in a complimentary manner, such that the area remains constant: $Scale_x$ * Scaley = 1)

For the calculations, the area for the building floor shapes were considered to be around 550 sq. m which is the standard area for most residential and few commercial buildings in West Bengal. The radiation calculation was done using **Ladybug –** A climate based plugin for Rhino-grasshopper. The simulation by the evolutionary solver was terminated after 20 generations for each case. Even though the range for building dimensions were kept to a minimum in each case, the resulting building floor areas deviated quite handsomely from the original 550 sq. m. So, to get proper comparisons between the building shapes, insolation/ sq. m of floor area was calculated, since originally the shapes considered had similar floor areas. The nine shapes considered more or less exhausts the types of building configurations found in Kolkata and so we get an extensive sample set for our study.

Table 1: Value of X, Y, Z for the nine shapes

Shape	Western Insolation (kWh/m^2 day)			Overhead-Eastern Insolation (kWh/m^2 day)			Perimeter intersection With Wind Rose (Z) (m)	Orientation (north to top of page)
	Summer (A)	Winter (B)	Difference (X=A-B)	Summer (C)	Winter (D)	Difference (Y=C-D)		
U	499875	130561	369314	755478	219045	536433	72419	182
H	614037	154752	459285	921334	256858	664476	92163	0
Courtyard	610205	162215	447990	926101	273804	652297	140629	89
L	441791	116147	325644	666693	191174	475519	72239	108
Plus	502455	137483	364972	757108	230169	526939	97099	176
T	453890	124980	328910	672878	199150	473782	70025	349
Truncated	522500	138065	384435	792815	229491	563324	69348	12
Triangle	494585	127868	366717	749497	222383	527114	77392	258
Trapezium	473047	119366	353681	714380	200440	513940	63686	283

Table 2. Final results from the optimizations

Shape	Initial Floor Area (sq. m)	Floor Area after Optimization (F) (sq. m)	Total Summer Insolation Per Unit Floor Area S=[(A+C)/F] (kWh/m^{4}day)	Total Winter Insolation Per Unit Floor Area W=[(B+D)/F] (kWh/m^{4}day)	S-W (kWh/ m^{4}day)	P= Perimeter (m)	Q = Area (sq. m)	Perimeter to area ratio = P/Q (1/m)
U	550	438	2869	799	2070	98	437.5	0.22
H	550	538	2854	765	2089	130	538	0.24
Courtyard	550	546	2814	799	2015	137	546	0.25
L	550	360	3079	854	2225	89	360	0.25
Plus	550	386	3267	954	2313	118.9	385.5	0.3
T	550	350	3219	926	2293	98	350	0.28
Truncated	550	491	2679	747	1932	91	491	0.19
Triangle	550	415	2998	844	2154	96	415	0.23
Trapezium	550	422	2814	758	2056	83	422	0.20

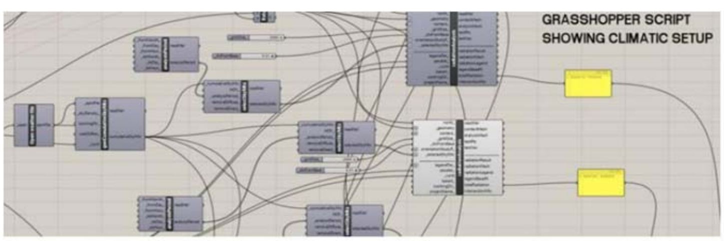

Fig. 1. Grasshopper Script part 1

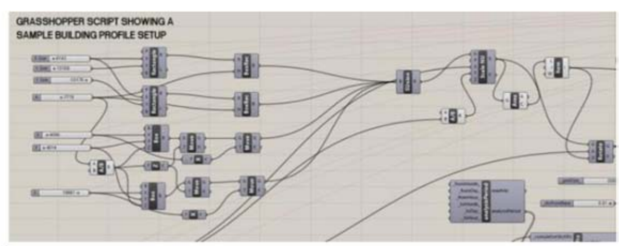

Fig. 2. Grasshopper Script part 2

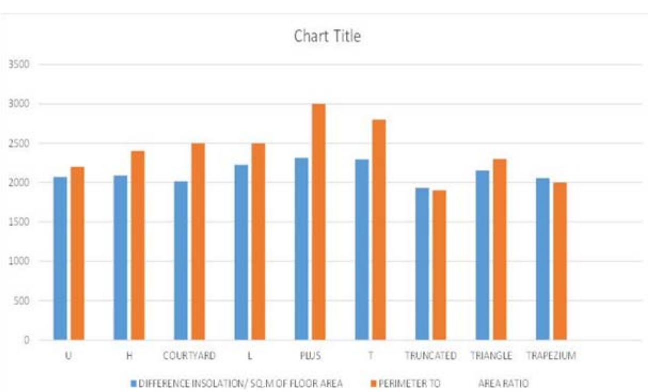

Fig. 3: Comparison between (S-W) and (P/Q)* 104

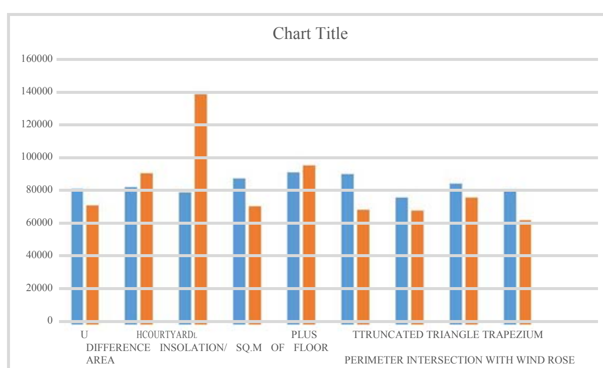

Fig. 4: **Comparison between (S-W)*40 and Z**

optimum and climate responsive building shape. But the odd shape presents a difficulty for functional use of the space. Also, the low perimeter to area ratio accounts for low wind ventilation, which is not desirable in the warm-humid climate. Thus during practical application, some changes and deviations from the original form need to made.

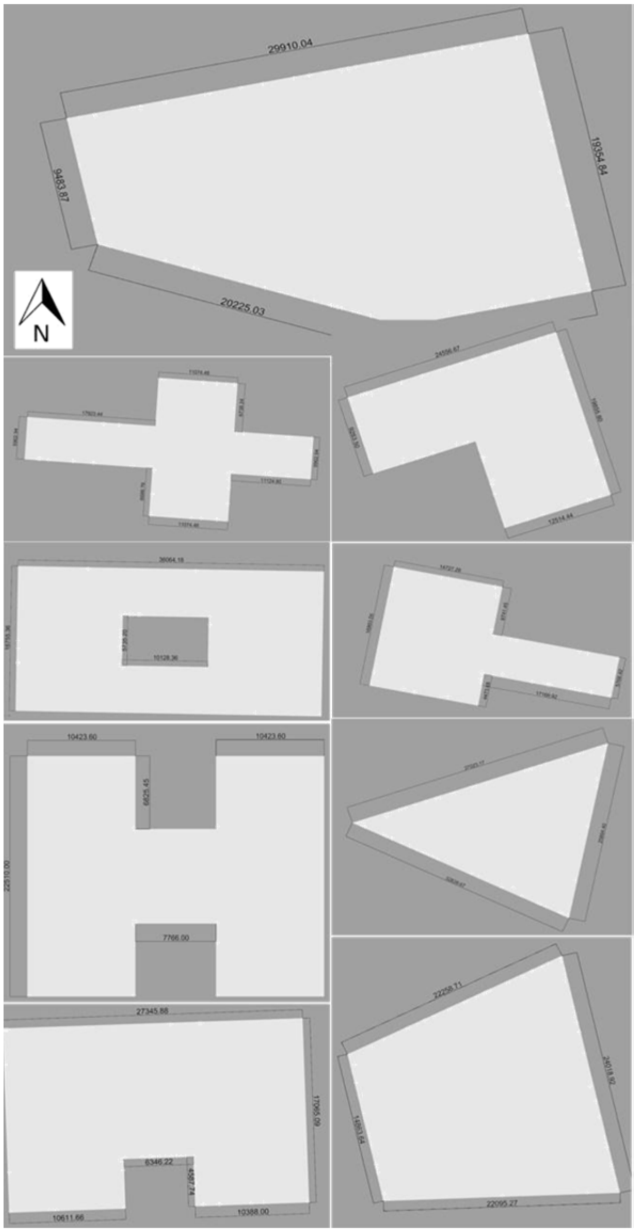

Fig. 5. The nine shapes in their optimised proportions

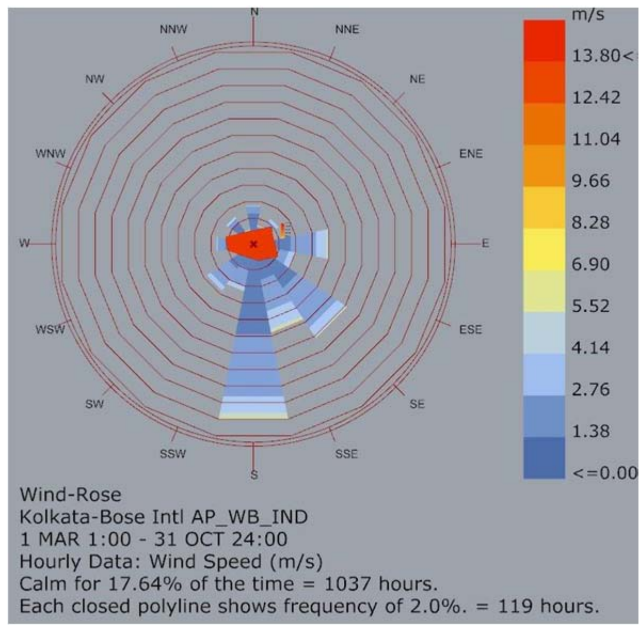

Fig. 6. Wind Rose shown for truncated shape

The basic form, geometry and proportions can be emulated during the construction of buildings in real life. A few changes are obviously necessary during the planning of functional zones within this specified form.

4. CONCLUSION

An obvious pattern is apparent from the charts above. The forms with the higher perimeter to area ratios have a higher insolation gain while the forms with the lower perimeter to area ratios have lower insolation gains. From the charts above, it can be concluded that the **TRUNCATED** shaped building shape has the lowest difference between summer and winter insolation which also conforms to the fact that it has the lowest perimeter to area ratio, while the plus shaped form having the highest perimeter to area ratio accounts for the highest insolation. So, the truncated shape can be labelled as the most

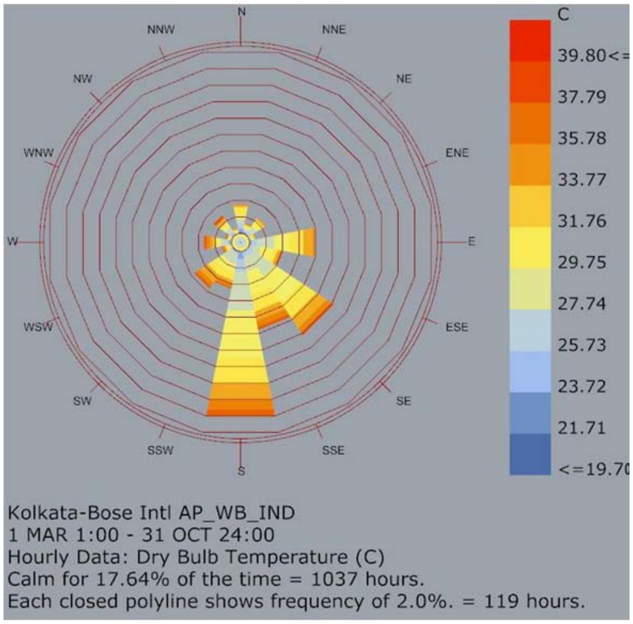

Fig. 7. Dry bulb temperature shown for truncated shape

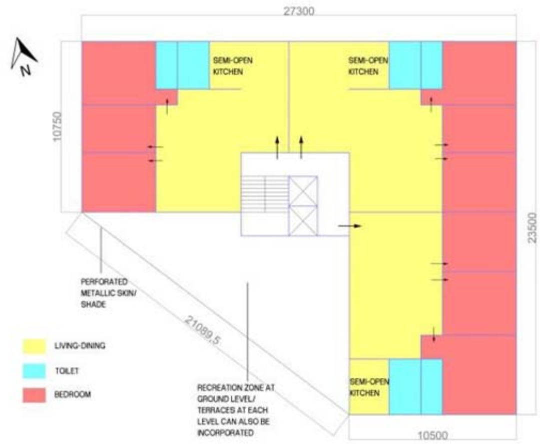

Fig. 8. The functionality of a 3 unit residential building within the optimized form

The functional layout of the spaces within the units has been marked. The dimensions show the slight deviations in the proportions of the shape from the original optimised plus form. The exterior form of the layout can be kept as a truncated quadrilateral to reduce the heat gain. A perforated screen can be implemented as shown thus reducing the internal form to an L-shaped layout which has a perimeter to area ratio of **0.25 as opposed to the 0.19** for truncated, thus increasing rates of ventilation within the unit. The excess space can be used as a recreational zone at ground level or for terraces at multiple levels to increase social interaction.

5. LIMITATIONS

The entire analysis and inference done above has been based entirely on computer simulations without any real-life data. Collection of such data is a lengthy process which is being currently conducted and can be included in the next version. Another drawback of this paper is the comparison between the final optimised forms. The optimised shapes have different floor areas as opposed to the same initial floor areas. Even though an attempt has been made to compare them based on unit floor area, it provides for a scope of improvement. The final and major drawback of this study is that the analysis has been done mostly in a 2-d format. Similar height of the shapes have been considered but the change in building physics along with the height has not been considered. Also, other than the wind rose no other ventilation parameter or software has been used for this study.

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