Dynamic Structures

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ABSTRACT

The paper reports on a series of short projects undertaken in the course of the 2006-07 academic year as part of the AA School's Masters Programme in Sustainable Environmental Design. The objective was to explore the architectural potential of adaptive comfort in the extreme climatic conditions of the Gulf Region. The first set of projects focused on designs for *transitional structures* conceived as means of alleviating the thermal discontinuities between the heavily airconditioned buildings and the high ambient temperatures common to this climatic region. A prototype such structure was fabricated and tested on location in the Region in February 2007. The experience of designing and making this structure helped inform a set of parametric studies using a dynamic thermal simulation model. In turn the results of the parametric studies guided the development of building design proposals for sites on Lulu Island in Abu Dhabi.

1. INTRODUCTION

Contemporary buildings in the Gulf Region are characterised by their strong dependence on mechanical airconditioning. The AC equipment is commonly set to maintain rooms at temperatures in the region of 22-24°C. With ambient temperatures rising to mean values of some 35°C in the hot period of the year, and daily maxima above 40°C, the resulting temperature differences between indoors and outdoors will often reach or exceed 20K. In cities such as Dubai and Abu Dhabi, the rapidly increasing heat discharges from AC equipment that the very fast growth of these cities has entailed, combined with high values of daily solar radiation absorbed by road and building surfaces, are major contributors to urban warming. This then translates into even higher cooling loads for buildings. Such vicious circle accentuates a noticeable alienation from the outdoor urban environment. To win back the use and enjoyment of the city the climatic differences between indoor and outdoor spaces need to be narrowed. This became the working hypothesis for the projects described in this paper.

2. CONTEXT

2.1 Climate

Weather data for Abu Dhabi City (24.28°N 54.25°E), Fig. 1, highlight three distinct periods: a four-month period of *mild* weather (December to March inclusive) characterised by mean daily ambient temperatures of 20-23°C, a *warm* period (November and April) with mean ambient temperatures of 25-26°C and a *hot* period (May-October inclusive) with daily means of 30-35°C. The diurnal temperature range is of 10-12K with night-time minima below 25°C on most months except the three month period June-August when night-time temperatures can exceed 27°C. Sunshine is strong throughout the year with an annual average of 8 hours of bright sunshine per day, rising to 10 hours/day in the hot period. Daily values of global solar radiation on the horizontal are in the range of 3.7-7.0 kWh/m^2. Winds average above 4.0m/s throughout the year with the strongest coming from the direction of the Gulf (Northerly and North-westerly) on most months. The daily values of relative humidity of 50-65% conceal high levels of absolute humidi-

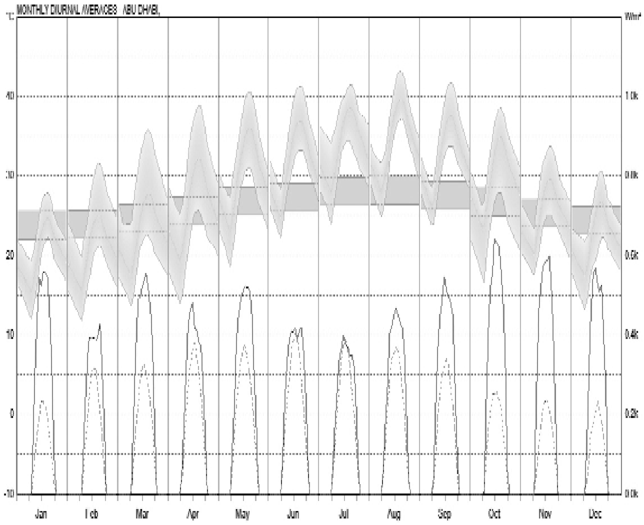

Fig. 1: Daily max and min ambient temperatures (adaptive comfort zone in background) and direct (solid lines) and diffuse solar radiation on horizontal for Abu Dhabi (Source: Meteonorm v5.1 data plotted with WeatherTool)

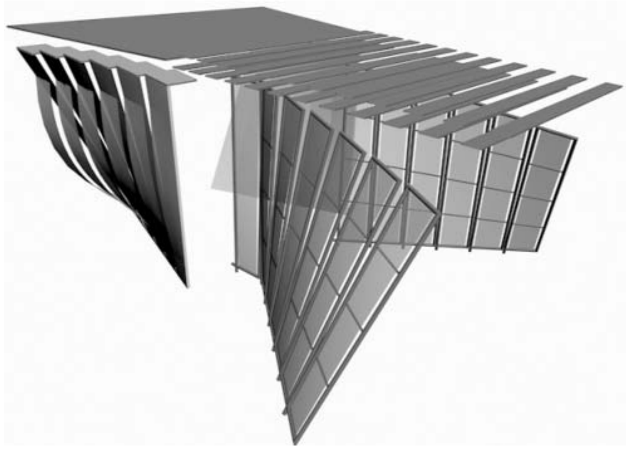

Fig. 2: Schematic illustration of static and dynamic components of a transitional structure.

ty of 15-25 g/kg in the hot period. At the peak of the hot period the wet-bulb temperature rises to 24-25^{o}C which is a limiting range for direct evaporative cooling. The prospects for evaporative cooling are better in other parts of the year when the daily values of the wet-bulb are around 20^{o}C. Sky temperature depressions are in the range of 10-12K throughout the hot period suggesting there could be a useful potential for radiative cooling.

The mean sky luminance has an annual average of about 25,000 lx, rising above 100,000 lx in the summer period of which about half is diffuse illuminance from the sky vault. Under these conditions 1-2% of the outdoor illuminance can be sufficient to provide the illumination levels of 300-500 lx required for typical indoor activities.

2.2 Comfort

Calculation of PMV and PPD values shows that thermal comfort conditions as defined by the ISO 7730 and the ASHRAE Standard 55-92 can be achieved with air and mean radiant temperatures in the range of 19-30^{o}C when the other variables are suitably adjusted to reflect common human adaptive behaviour (Yannas 2007). Similarly, calculation of monthly neutral temperatures for Abu Dhabi using Auliciems' empirical equation (Auliciems and Szokolay 1997) shows these to vary in the range 23.8-28.1^{o}C. Allowing for comfort zones that extend by +/-2K about these values gives an adaptive comfort range of 22-30^{o}C over the annual cycle. There is no fundamental difference between the results obtained using either the PMV / PPD calculation or the empirical equations of the adaptive model.

3. PROJECTS

3.1 Transitional Structures

The first set of projects focused on transitional structures including canopies, arcades, pavilions, bus shelters, courtyards and patios. These were analysed in terms of typological and constructional features with reference to their role in environmental control. Designs for several such structures were put forward by the five student teams. Dynamic attributes that would allow such structures to respond to daily and seasonal variations in environmental conditions and to occupant requirements were identified, Fig. 2. Good features singled out by the project teams in the course of this first stage were then drawn together into a prototype design that involved all of the teams as a single work group. In the course of an intensive one-week period the group finalised its design and fabricated the prototype at the AA School's Hooke Park building laboratories in Dorset. The components of the structure were then carried as hand luggage to the UAE where the structure was assembled for testing on the campus of the American University of Sharjah. Dataloggers were installed to take temperature readings over the period of the visit. However, there was little time for detailed testing of the

Fig. 3: Design, making and testing of the lightweight transitional structure.

structure's environmental performance and the group had only a few hours in which to experiment with its operable features which allow full occupant control of canvas surfaces to regulate solar protection, air flow and nightime cooling by convection and radiation, Fig. 3.

3.2 Building Design Strategies

In embarking on the next set of projects, the following were identified as key considerations.

- *Adaptive measures for thermal comfort:* project teams to redefine these according to the specific spatial and temporal characteristics of occupant activities foreseen by their chosen building programme.
- *Glazed openings* to be sized and shaped to provide adequate daylighting for the activities of the selected building programme.
- *Solar control* to be considered on all orientations.
- *Internal heat gains* to be mapped so that their origin, magnitudes and spatial and temporal distribution can be traced and potentially controlled.
- *Ventilation should be controllable*: air supply to be independent of window opening.
- *Air permeability* for convective cooling by

Fig. 4: View from Lulu Island toward Abu Dhabi city centre.

specially provided adjustable apertures; such apertures need not be glazed.
- *Ceiling fans* can help extend the upper limits of the adaptive comfort range.
- *Radiative cooling* appears to have potential in this location.
- *Evaporative cooling* potential is confined to a short period of the year.
- When no combination of the above is sufficient to provide comfort during occupancy, the spaces needing cooling should be zoned so that the energy used for mechanical airconditioning can be minimised.

A series of exploratory parametric studies were performed using the TAS dynamic thermal simulation model (EDSL 2006). These provided indications of the likely thermal performance to be expected from the application of the range of options listed above. The results of the simulations provided starting guidelines for the building design proposals that followed on Lulu Island.

3.3 Masterplanning and Building Proposals

Al Lulu Island, the object of the following set of projects is an uninhabited, manmade islet with an area of some 15 square kilometres, located a few hundred metres off the coast of Abu Dhabi in view of the city centre, Fig. 4. On a study trip to the UAE in February 2007, our group visited the island and studied the latest proposals for its development. Project briefs for this stage were established in the course of a two-day seminar in Abu Dhabi. The seminar discussions highlighted the importance of the following four notions which seemed to apply in varying degrees to both architectural and urban design considerations:

- *transitions:* between land uses, between indoors and outdoors (space and time-dependent adaptive mechanisms)
- *permeability:* of urban tissue, of building fabric, of indoor tissue (space and time-dependent or permanent responses to air and moisture transfer)
- *separation:* spatial zoning of land uses, zoning of indoor spaces, degree of coupling between indoors and outdoors (space and time-dependent or permanent degrees of coupling or isolation)
- *identity:* materiality, expression, relevance (architectural, environmental, sociocultural).

Project teams were asked to make proposals for the development of building programmes on Lulu island, either within the developer's current masterplan or as alternatives to that masterplan. Six of the resulting schemes are illustrated here, Figs 5-6.

- The scheme by Surane Gunasekara and Yuan-Chun Lan, Fig. 5 (top row) leaves the island as a public resort for the city, confining new development to floating platforms that form the links with the city of Abu Dhabi. A stepped reduction in built density is illustrated by the scheme tending to low-rise development on the island side of the platforms. Strong environmental considerations characterise the building design.
- The proposal for a stadium on Lulu Island by Krista Raines, Fig. 5 (middle row) follows from her masterplan with Annisa Julison to develop the island as an Olympic Sports Complex. Multilayered solar protection and good air flow potential are key considerations for the stadium design and were based on mapping of the daily and seasonal schedules of sporting activities.
- The scheme by Yasamin Arbabi, Fig. 5 (bottom row) is for a high-density, low-rise residential cluster based on her masterplan for the island developed with Harsh Thapar. The proposals

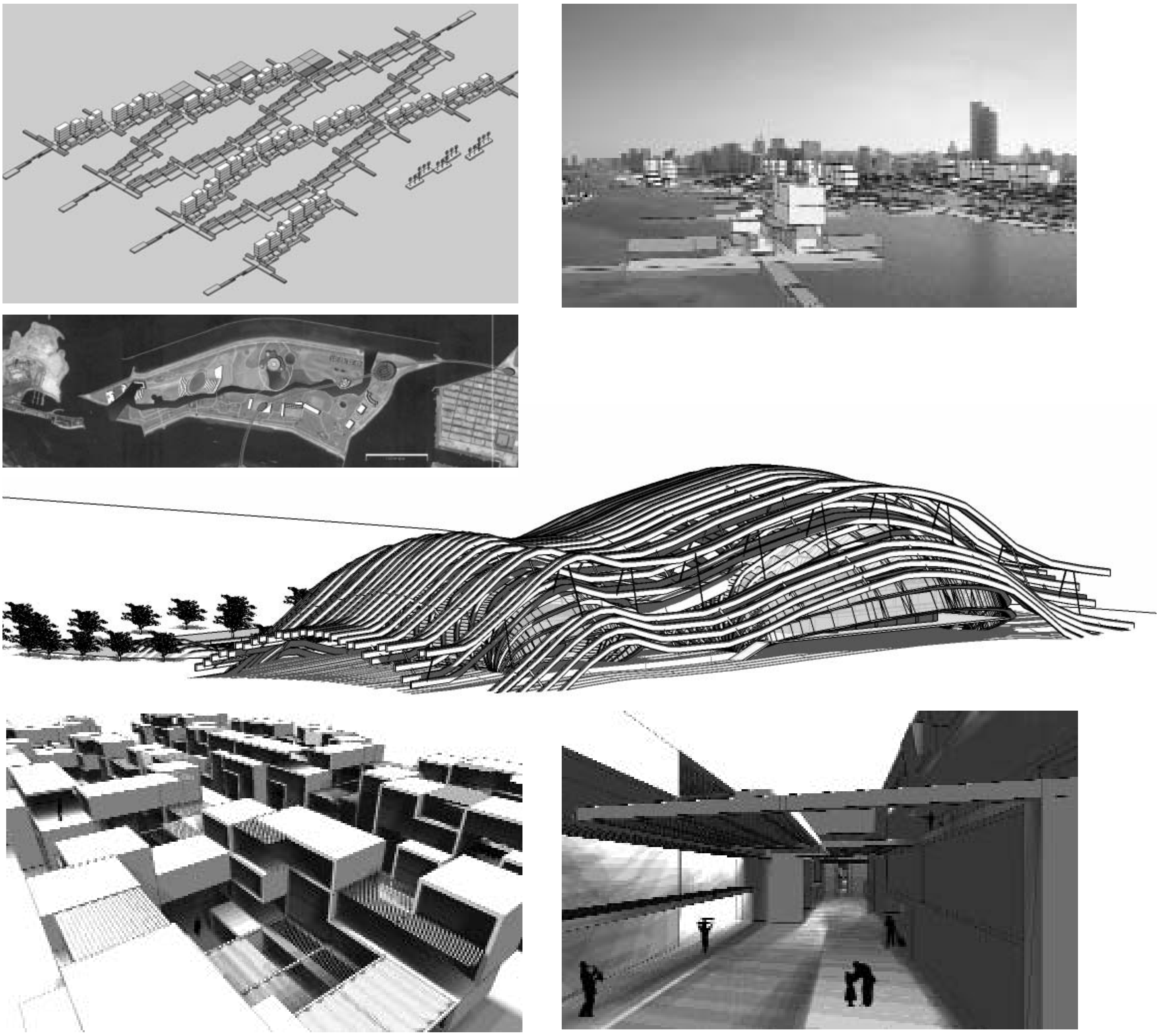

Fig. 5: Design proposals relating to Lulu Island, Abu Dhabi

make extensive use of private and public transitional spaces that help ensure solar protection and good airflow through the cluster.

- The proposal by Kanika Agarwal and Vidhi Gupta, Fig. 6 (top row) gives part of the Gulf side of the island to a holiday resort. This takes the form of variable transitional and semi-open spaces for daytime and night-time use.
- The scheme by Tiffany Broyles and Anya Thomas, Fig. 6 (middle row) proposes the development of second homes along a beach "boardwalk" that includes provision of sheltered transitional spaces for public use. A variable permeability of the building skin is envisaged to regulate light and air flow.
- The shaded walkway by Farah Naz, Fig. 6 (bottom row), illustrates one of the transitional spaces on her scheme with Lydia Yiannoulopoulou for a low-rise, pedestrian islet combining home-office blocks and commercial elements along access paths.

4. CONCLUSION

The extreme climatic conditions and adherence to artificially conditioned environments that characterise the intense building activity taking place in the UAE makes the Gulf Region a most challenging context yet for any consideration of sustainable design.

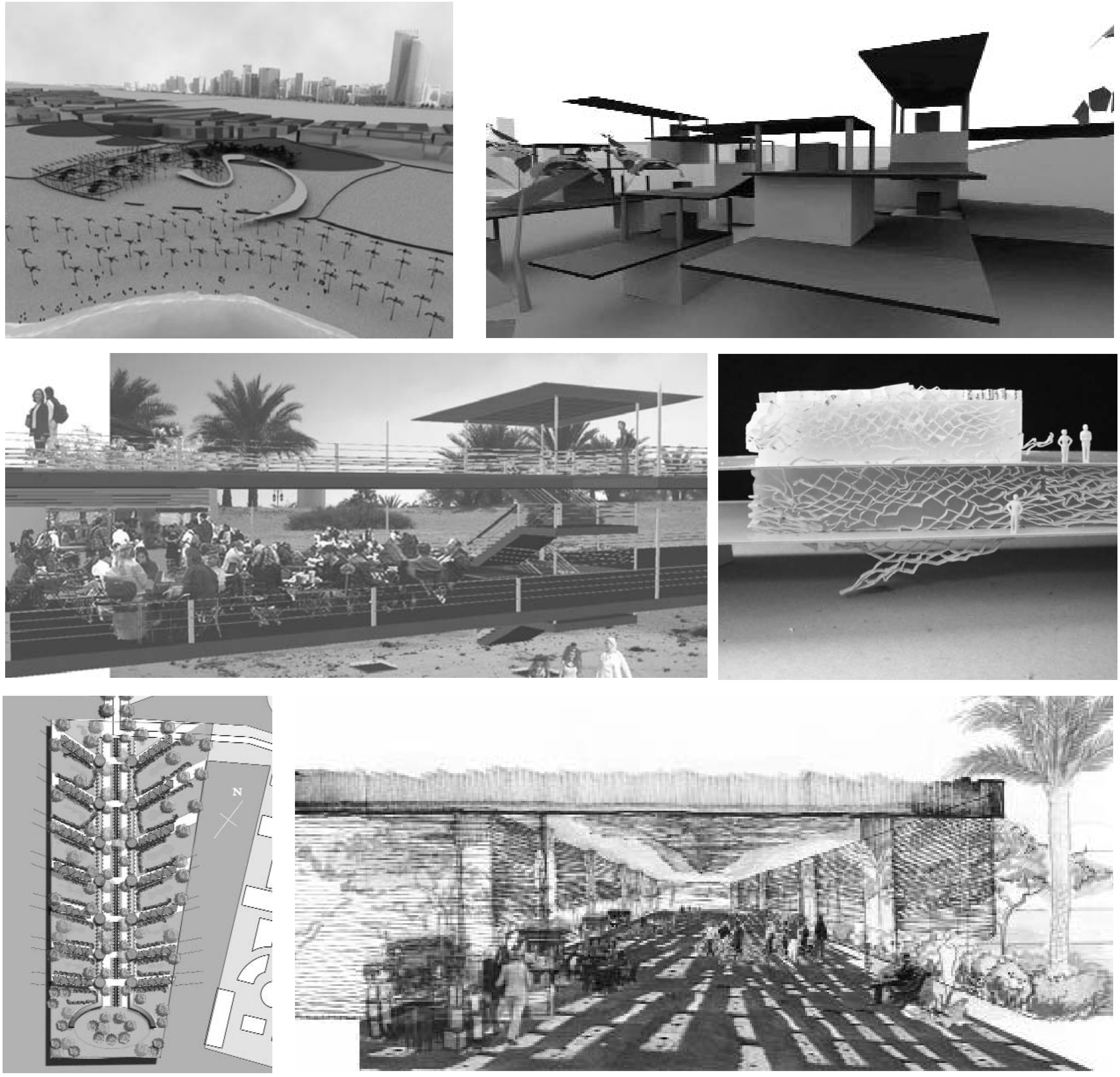

Fig. 6: Design proposals relating to Lulu Island, Abu Dhabi.

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