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Larry Ng, associate principal, joined Cesar Pelli & Associates almost 25 years ago. Since that time, he has served as project manager and design team leader for the architectural design and master planning of more than 43 million square feet (4 million square meters) of large-scale commercial developments. He is currently design team leader for a 1,050-foot (320-meter) residential tower and a 1,250-foot (380-meter) office tower, both in the United Arab Emirates. He has just completed the design of the 820-foot (250-meter) Torre de Cristal in Madrid, Spain, and 4,305,000-square-foot (400,000-square-meter) new office development and public spaces at Canary Wharf in London.

Mr. Ng served as the project manager for the International Finance Centre in Hong Kong and the Petronas Twin Towers and Dewan Filharmonik Petronas in Kuala Lumpur, Malaysia.

His education includes a Bachelor of Architecture from Cornell University, a Masters of Architecture from Yale University, and a Master of Science in Real Estate Finance from New York University. Mr. Ng has spoken at the 1999, 2003, and 2004 CTBUH international conferences; the 2002 CIB Global Leaders Summit on Tall Buildings in London; and the FIABCI 2002 53rd World Congress in Kuala Lumpur. He is also a frequent speaker at international stainless steel and natural stone conferences. He has contributed articles to professional journals including *Laminated Glass News* and *Stainless Building Bulletin*. Mr. Ng is a regular guest lecturer at Yale University and Cornell University.

An Aesthetics of Sustainability

Architecture is an art of response — a creative and poetic response to the program requirements, site conditions, and most importantly, the spirit and culture of the place. We not only want our architecture to be beautiful, we also want it to be contextually relevant and environmentally responsible.

Today, users and occupants place much greater focus on the comfort of the working and living environment, not only in terms of thermal comfort but also visual comfort. There is also a strong desire for the integration between the exterior and the interior environment.

Cesar Pelli recently completed the design of two tall buildings: one in Madrid and one in the United Arab Emirates, both extreme climatic conditions. Both projects have to reconcile the desire for transparency with the demand for physical comfort and concerns for energy. To achieve this objective, the Madrid project incorporates a lot of active measures, such as ventilated double wall, on-floor air intake and air exhaust, and the use of photovoltaic panels; whereas the project in the Emirates relies heavily on passive measures, such as extensive canopy covers, natural cooling effect from height, various forms of solar protections to reduce glare, and direct heat gain to achieve the same objective.

An Aesthetics of Sustainability

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Our firm recently completed the design of two tall buildings: one in Madrid and the other in the Emirates. Both projects will have to reconcile the desire for transparency, and the demand for physical comfort. To achieve this objective, the Madrid project employs a lot of *active* measures, such as ventilated double wall, on-floor, on demand air intake and air exhaust, and the use of photovoltaic panels. The project in the Emirates relies heavily on *passive* measures, such as natural cooling effect from temperature gradient, and various forms of solar protection to reduce glare and direct heat gain.

Madrid is located at the exact geographical center of the Iberia Peninsula. Its average altitude is 654 meters above sea level. During the cold season, the minimum temperatures often fall below freezing point, although the city rarely snows. During the summer months, the temperature often reaches 40 degrees C. and above. It is one of the world's hottest cities in the summer; this is however made more bearable by the extremely low humidity level. Madrid also boasts an average of 2800 hours of sunshine yearly. These climatic conditions pose some rather unique challenges to the design of a tall tower with a glass curtain wall, especially when the orientation of the tower was dictated by the master plan, which cannot be altered.

Torre de Cristal occupies one of the four sites at the former Real Madrid training field on Paseo Castellana, the major boulevard leading to the center city. The tower is 250 meters in height, with 45 occupiable office floors. For the design of Torre de Cristal, we searched for a form that is both sculptural and iconic, a form that would come to life under the strong Iberian sun. The sculptural facades of glass and anodized aluminium will glow and glisten like facets of a crystal.

The shape and profile of a tall building determines its performance in wind. The shape of the tower not only affects the loading on structure and cladding, it also impacts on its surroundings. The sculptural facets of the tower, with its tapering profile, greatly reduce downdraughts from the surface of the tower and thus improve the quality of the pedestrian environment at ground level. This is a lesson we learnt from the design of One Canada Square at Canary Wharf in London, where the form is an extruded square. The faceted form also reduces the wind pressure on the cladding, and permits the use of thinner glass panels on the curtain wall. This is an important consideration as the size of the curtain wall panels averages 2400mm x 4200mm. The corresponding wind pressure on the cladding for a rectangular tower, such as One Canada Square, would have been 25% to 35% higher.

There are two active features built into the design of the exterior wall: first, on-floor, on demand air intake and air exhaust; and second, the use of a ventilated double wall.

In Madrid, the office hours vary from company to company, as does the timing of summer holidays. To minimize the consumption of energy, it makes sense to allow each tenant the flexibility to control air intake and air exhaust, depending on their hours of operation. This is especially ideal considering the dryness of the

Madrid climate, where excessive leakage from rain is not an important consideration.

In Madrid, the controlling factor is the summer months, where one will have to deal with not only outdoor temperatures above 40 degree C. but also the issue of glare. The most effective means to control heat gain is the use of external shading, where solar radiation is intercepted before it even enters the building. Site constraints do not permit the installation of exterior sunshades. In the absence of which, the most effective form of heat control is a ventilated double wall used in conjunction with high performance coating on sealed double glazed units.

Since 53% of all energy in the solar spectrum is in the visible light spectrum, it is not possible to decrease total radiation transmission through the glass without affecting light transmission. The choice of high performance coating is therefore a delicate balancing act. We selected a high performance coating with a solar factor of 0.27 and a U-value of 1.3, applied on low-iron glass. While the total solar heat transmission increases from 27% to 28% with the use of low-iron glass, the actual light transmission increases from 47% to 52%, compared to the use of normal float glass. The low-iron glass also gives the tower a more crystalline appearance demanded by the aesthetic design intent.

In both summer and winter conditions, since the air inside the ventilated cavity is supplied at a room temperature of approx. 24 degree C., the surface temperature of the inner operable glass panel will always be within 1 to 2 degree C. of room temperature. At times of high solar radiation, the blinds in a down position reflect some high frequency short wave radiation (the major heat bearing component of the solar spectrum) through the glass and absorb the remaining high frequency solar radiation and re-radiate it back as sensible heat. It is therefore crucial that the blinds need to have a minimum 50% reflectance, and the air slot in the ventilated cavity be located adjacent to the external glass surface. Unlike the internal blinds in a normal sealed double glazing assembly, this sensible heat is extracted by continuous air flow within the cavity, ventilated at a rate of 50 cubic meters per hour, per lineal meter, in the case of this project. The inner operable glass panel also acts as a good barrier to prevent low frequency long wave radiation from entering the room. Once direct solar radiation enters the room, it is not possible to air condition against direct solar radiation.

Occupant comfort is further enhanced by low velocity displacement ventilation at the floor level, where conditioned air is supplied to the area where it is most needed. Air supply at the floor level also allows users to adjust the volume of air flow at each work station.

In the summer months, when the air temperature inside the top of the ventilated cavity will likely be in the range of 29 degree C. to 30 degree C., it is much more energy efficient to discharge the ventilated air to the outside. In the winter months, with air temperatures inside the ventilated cavity in the range of 26 degree C. to 27 degree C., it is feasible to channel this extract air to the heat exchanger to recover some of the heat.

The other important consideration is the issue of glare control, as it has material impact on the use of computers. The tower is equipped with automatic blind control, synchronized for each façade as the sun angle changes.

Prior to the submission of Projecto Basico, the City of Madrid passed a by-law requiring that all hot water for the toilet rooms be generated by renewable energy sources. The south facing inclined plane at the roof top has a total of 250 square meters of photovoltaic poly-crystalline solar cells, used in a laminated glass panel assembly. Each square meter of solar cell generates 120 watts of electricity. The main advantage of PV technology is its ability to convert sunlight directly into electricity. This is especially ideal for a situation like Madrid, where it averages 2800 hours of sunshine per year. Since the landlord is charging tenants for their use of electricity, we estimate the payback period will be approx. 14 to 16 years.

The desert environment of the Emirates poses some rather unique challenges to design. Unlike Madrid, the summer months are hot and humid, with day time temperature in the range of 40 to 45 degree C. and relative humidity close to 80% or higher. The desert environment is also characterized by a wide diurnal range of temperature. Other than the five summer months, the outdoor temperature is actually very comfortable for most of the year. If the design of the Madrid project is an exercise in adopting technology to achieve sustainable design, the design of the project in the Emirates is an exercise in learning from the vernacular.

As recent as the 1950s, the Gulf region was marked by vernacular houses with courtyards and wind towers, using extensive shading devices and screening elements, using natural ventilation via temperature gradient as means of providing comfort.

The project is 330 meters in height, with offices at the lower levels and residential apartments above. The site is spectacular with panoramic views of the Corniche, overlooking the turquoise water of the Gulf beyond. To optimize the view, the tower is placed perpendicular to the Corniche to afford all occupants with a view to the water. In contrast to the crystalline quality of the Madrid project, the project in the Emirates is conceived as a layering of screen elements, unfolding like petals of a flower to reveal a crystalline pillar. Similar to the Madrid project, the massing is gently tapered towards the top.

In respect of the waterfront park, the base of the tower is designed as a series of garden terraces, under the protection of a huge canopy cover. The canopy cover offers shade and glare reduction to the office spaces occupying the lower levels of the tower. The office spaces are organized around an internal atrium, similar to the traditional courtyard architecture of the region. The canopy cover intercepts direct solar radiation and reduces solar heat gain and cooling load required to cool the atrium and public lobbies.

Similar to the Madrid project, the office floors are equipped with a ventilated double wall system. As the air inside the ventilated cavity is supplied at room temperature, the surface temperature of the inner operable glass panel will always be within 1 to 2 degree C. of room temperature, although the rate of air flow in this case will likely be in the range of 60 cubic meters per hour, because of the high exterior ambient temperature and the higher absorbed energy within the air cavity. Again, we selected a high performance coating with a solar factor of 0.27 and a U-value of 1.3, which is appropriate for such climate.

At the residential apartments, shading devices are provided by continuous balcony projections, which intercept the direct solar radiation before it enters the habitable spaces. In addition, there is a painted aluminum screen wall located on the exterior of the balcony wall as an additional screening element. Similar to the local vernacular built forms, these screen elements add a layer of visual richness and a sense of place to the architecture.

The pool and the health club are placed at the top of the tower, at approximately 280 meters above grade level, to take full advantage of the natural temperature gradient and the higher wind speed at that height, a concept not dissimilar from the traditional wind towers in the Gulf region.

Architecture is both conditioned and conditioning; it is inevitably influenced by its social cultural context. We believe architecture is an art of response, a poetic and artistic response to the project's aspirations, to the site, to the culture and spirit of the place and most importantly, to the moral values of our time. Our concern for sustainability is no doubt creating a new visual paradigm. What makes an art form compelling is its relevance.