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Burj Dubai: Designing the World's Tallest

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Biography

Adrian Smith, has been a practicing architect for over 40 years. His extraordinary body of work includes some of the world's most recognizable landmark structures, including the Jin Mao Tower in Shanghai, China; Rowes Wharf in Boston, Massachusetts and the Burj Dubai in the United Arab Emirates, soon to be the world's tallest structure.

Adrian's unique design approach emphasizes sensitivity to the physical environment. He considers each project holistically, taking into consideration site orientation, climate and geography, cultural and social influences to create highly sustainable projects that achieve contextualism within the global environment. As one of the world's foremost experts of super tall towers, he recently collaborated with Gordon Gill to design the world's first net Zero-Energy skyscraper, Pearl River Tower, to be built in Guangzhou China. The design harvests the natural forces of wind, sun and geothermal mass, and continues Adrian's tradition of integrating energy efficient systems and technologies into his designs.

Prior to founding Adrian Smith + Gordon Gill Architecture in 2006, Adrian was a Design Partner in the Chicago office of Skidmore, Owings & Merrill from 1980 to 2003 and a Consulting Design Partner from 2004 to 2006.

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Abstract
When completed in 2008, the Burj Dubai will be the tallest building in the world and a new landmark for Dubai and the United Arab Emirates. The tower's organic form was derived from the culture and landscape of the region, strongly connecting the building to the surrounding context. A mixed-use tower, the Burj Dubai features an efficient Y-shaped floor plan that maximizes views of the city of Dubai. The tower also addresses environmental concerns and features an innovative condensation collection system.

This paper discusses the process of the building's design, offering insights into the refinement and development of the design in response to programmatic requirements, structural wind-tunnel testing and other issues related to the design of a country's landmark and the world's tallest structure.

Keywords: World's Tallest Building

Introduction

SOM was first contacted by Mark Amarault and Robert Booth in the spring of 2002 to arrange an interview with them to discuss the possibility of designing the Burj Dubai. They had seen the Jin Mao Tower in China, which the author of this paper had designed several years earlier. Bill Baker, George Efstathiou and the author met them in New York and showed them several super tall buildings that we had designed, both residential and mixed use. We talked about the importance of architectural and structural integration to achieve an efficient and affordable design. At the end of the interview they asked me how they should decide which architect to choose since they had seen several they had interviewed that they thought were capable to do the job. I suggested they should have a two week ideas competition and select the scheme that they thought would meet their needs the best. A few weeks later they pursued that direction, we developed our concept, submitted it and we were selected. My understanding is that when EMAAR received the material from the competitors they displayed it and presented each concept to Mohammad Alabbar and the Directors of EMAAR and judged them on criteria including initial visual impact, buildability and cost. Our competitors were KPF from New York, Cesar Pelli from New Haven, Connecticut, Carlos Ott from Canada and Norr Architecture from Dubai.

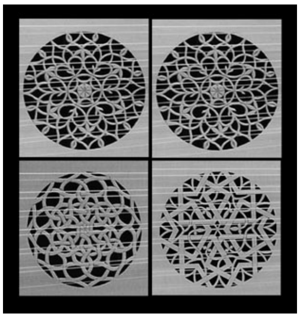
The Concept

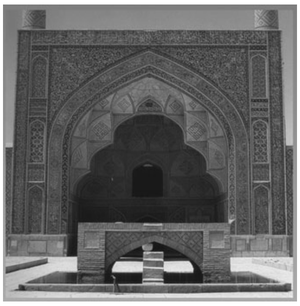
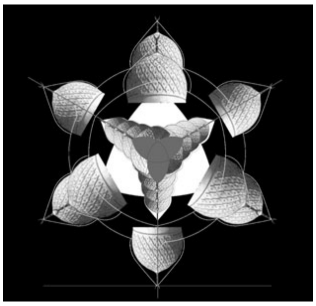
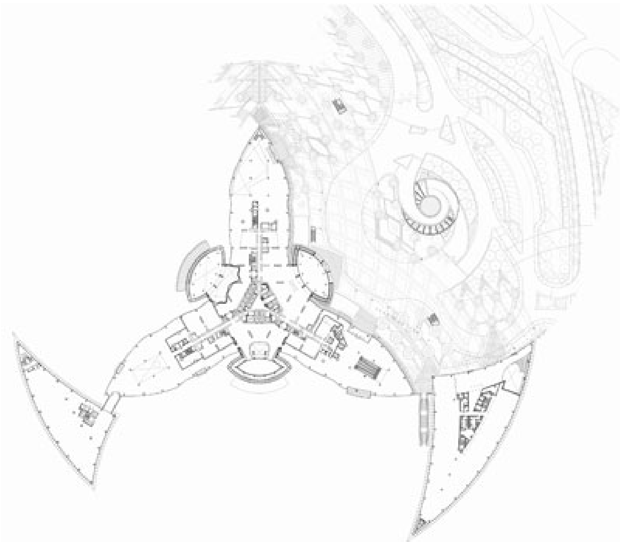
In developing the initial concept for Burj Dubai, I searched for elements within the existing context and culture of the area to reflect on and draw inspiration from. Within the Middle East and in Dubai, there are strong influences of onion domes and pointed arches, and there are patterns that are indigenous to the region, some of which are flower like with three elements, some with six and so on. Other influences range from spiral imagery and philosophy embedded in Middle Eastern iconographic architecture and motifs. These motifs have their origin in organic growth structures and plant materials.

The form is geometric in plan, starting with three branches and three pods. The specific shape of these branches is modular in nature and in function and organic and biomorphic in form. The form can be found in flower petals, leafs, seeds and animals such as birds, sea creatures, coruscations, etc. The overall composition is a vertical object reduced and transformed by spiral reduction of branch lengths until it reaches its central shaft at which point the shaft peels away to reveal a triptych configuration that erodes in a spiral manner until there is a single spire. The resulting impression is organic and plant like. This typology is indeterminate in its size and can be expanded vertically by adding modules to its base or continuing to divide the spire element.

Observed in silhouette, the setbacks connect the Burj Dubai to the surrounding city, both now and in the future. At the lower floors, the setbacks relate to existing low and mid rise buildings that characterize the current landscape. As the region grows and higher rise buildings are constructed, setbacks at the higher floors will ensure that the tower always remains connected to its context. As the building rises from the ground it wants to feel like it is being sculpted from the earth and crystallized into a vertical stalactite of glass and steel. Its base should be very dense and solid, reaching out to connect to the contours that are ascending to its base and expressing the enormous weight it is carrying above.

I felt that a tower of the height expected from EMAAR, to be the world's tallest tower, should somehow embody these indigenous forms and should also be organic in nature.



Figures 1-4 Images illustrating onion domes and pointed arches, the inspiration for the form of the Burj Dubai; Figure 5 Plan of the Burj Dubai Tower. *The Architecture of Adrian Smith*, p. 204-205.

To me "organic" means that it is a form that looks as though it is emerging from the ground and ascending vertically. The flower image comes from looking at the building in plan, or from the air looking down at the building. The reference to the Islamic dome structures can be seen when looking up at the legs or branches of the tower and looking at the plan of each section of the three legs of the building. The pointed dome form in plan became an ideal form for the development of bay like windows from individual units to provide a more panoramic view of the city and Gulf. This form also provided a surface at each bay that would reflect light without the use of large flat surfaces that can sometimes be disturbing to the viewer when the sun is reflected by them.

The Developer's Objectives

EMAAR had just finished developing the Marina project, a massive venture on the Gulf. Six towers in the range of 40 stories had been built, and from this experience the demand from people in Dubai to live and work in high rise structures was understood. After the Marina project, EMAAR embarked on a monumental project with over 500 acres and plans to build more than 30 million square feet on this piece of land. It felt that they needed a landmark structure in the form of a super tall building in order to give the entire project an identity and a critical mass. A tall tower would not only give the master plan an identity, but would also become the identity for EMAAR and the Country of Dubai. They later used the image of Burj Dubai in a highly successful advertising campaign in a select number of very high quality magazines on a worldwide basis to help establish their own brand name.

It is very difficult for a developer to make money on a super tall building, that's one of the reasons why there are so few of them around. They are usually built for some other purpose such as a National Symbol or Landmark or as a catalyst for a much larger project where the tower itself may not make money but the sites around it will become more valuable. There are exceptional cases, like Burj Dubai, where the building will justify a high premium for its space. Even so, the building fundamentally must be designed to optimize all of it's systems to become affordable. The primary difference between a super tall tower and two towers half it's size is not the cost per square foot, although a super tall building will be more expensive on a square foot basis, it is the time it takes to build the tall one vs. two shorter ones and the cost of the money during that time and the loss of revenue through lost rent for the time difference that makes most super tall buildings unfeasible financially.

Figures 6 Burj Dubai Tower © Emaar Properties PJSC. *The Architecture of Adrian Smith*, p. 209.

Structural Integration

The integration of Architectural and structural concepts are essential in the design of super tall structures.

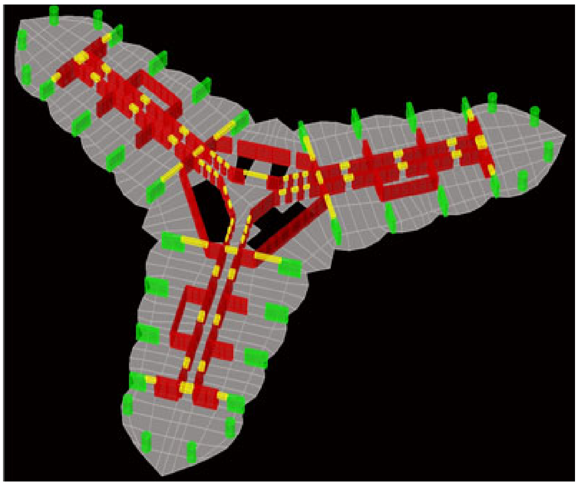
For a project to be viable, the building needs to be well suited for the functions it contains and the structure must be able to respond to the function it is supporting and it must be cost effective or else the project may not be viable. The structure is modular in nature with a central hexagonal shaft or core and three branches that spread out at 120 degrees from each other. Attached to these branches are wall like columns at 9 meter spacing that simply drop off as each leg sets back, avoiding complex and costly structural transfers. One of the key issues in the structural design of super tall buildings is that the building has the shape necessary to shed negative wind forces imposed on it by the wind moving around the building. Commonly known as vortices, these are the forces that move a building from side to side. This is not the movement that one expects from the wind trying to blow the tower over, it is a wind force that, if not designed for, will create a sideways movement that is rapid in it's frequency and thus of high acceleration; the kind of movement that makes the water in your sink move or the chandelier hanging from the ceiling swing. This is the kind of movement that if felt inside the building, makes the occupants very uncomfortable.

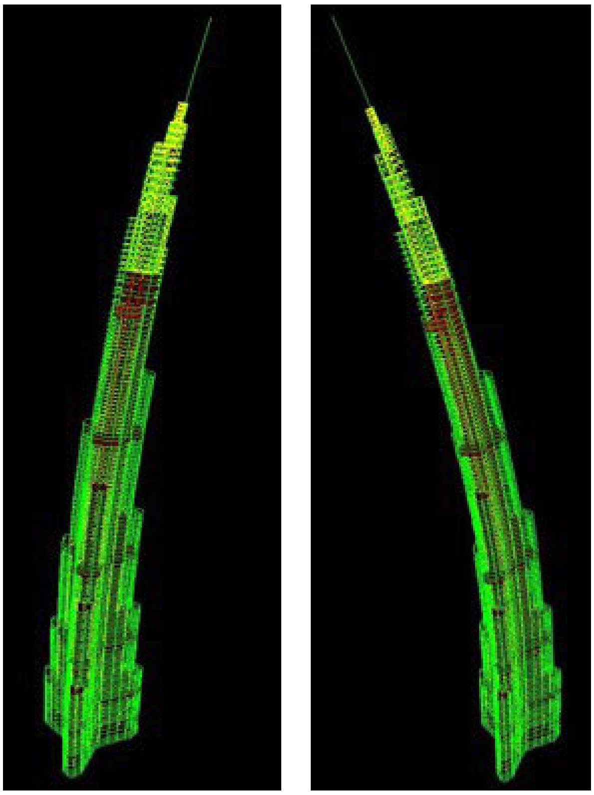
The shape of the building is very important in the mitigation of these forces and we tested, by wind tunnel test, several variations of the concept until we got the orientation and stepping system to optimum performance and to verify that the building shape is responding properly to the expected maximum winds expected on the site.

Other structural issues are to design for overturning, torsional movement and foundation stability.

Environmental Awareness

The building will feature an innovative condensate collection system. Hot and humid outside air, combined with the cooling requirements of the building, will result in a significant amount of condensation of moisture from the air. This condensed water will be collected and used for irrigation of the towers landscape plantings. This system will provide about 15 million gallons of supplemental water per year, equivalent to nearly 20 Olympic sized swimming pools.





Figures 7-9 Dynamic frequency analyses of Burj Dubai. *The Architecture of Adrian Smith*, p. 209.

Importance of Quality Execution

In my world there is no such thing as "just another skyscraper".

I believe that each building can be unique and can make a positive contribution to the society, whether it is ten stories or more than a hundred stories. Having said that, many more eyes will be watching a world icon and great care must go into the design and the execution of a countries landmark because it speaks to the viewer not only about its architect, but about its owner and about it's country. Therefore, there is little room for error on the part of any of the team members involved in its conception and execution.

Building Height

The strategy of not announcing the final height of the building has proven to be a very good one. Although the building did not at first get the publicity of other announced super tall structures because the height was confidential, since the building has now been under construction for more than a year, the press realizes that this is indeed a real building project and the confidentiality of the height has now become a positive talking point. There will be a final, definitive height at some point in time but it is the stated goal of EMAAR that this building be the tallest building in the world upon completion.

That said, there is excess capacity within the foundation system and the lower levels of the superstructure to add height to the building if needed to achieve that goal.

Security

There has been a lot of discussion in the media regarding post 9/11 construction of tall buildings and security measures that have been integrated into them. I am only aware of two tall buildings that have been terrorist targets. The Burj Dubai is a very robust structure and will be able to withstand great forces. However, I would hate to see this building or any other building be the subject of attack for any reason. Safety issues have been addressed however for security reasons they should not be discussed.

Design Development

In the scheme presented for the competition, the base of the Burj Dubai was geometric in form and contained a large area for parking, ballroom and other hotel functions. The office program was added after the competition was awarded and parking was later put below grade. Grade was artificial as we now define it since we brought grade up and over the parking functions in a spiraling manner so that each entry pavilion was accessed at a different grade level.

Not only did the Tower spiral upward but the grade spiraled around the tower base as well.

The site at the lowest grade level was developed into a field of fountains and geometric islands that contain landscape and walkways that connect the islands. This level became the office entrance and it is the lowest because it relates to the lake side of the Master plan. Located in between the lowest level and the intermediate level is the Hotel Health Club, spa, tennis courts and outdoor swimming pool. At the intermediate level is the residential entrance and drop off. Continuing around the tower in a clockwise rotation to the third and highest grade level is the hotel entrance and drop off and auxiliary office building entrance. This office building and the hotel spa building together are shaped in plan to form a circular shape when combined with the overall site plan. They are located in a way to further separate each level change and to help to give identity and orientation to the tower base.

The Pavilions

The focal point of each entry is the Pavilion structure. These buildings are consistent with the geometry of the tower but very different in all other respects. The tower is reflective while the pavilions transparent and crystalline. The pavilion structure is cable supported using the lightest structural system possible while the tower is concrete, solid and robust.

The pavilion will take in light, manipulate it and tame its effect on the interior environment. It will create many shades of light and dark and at night the pavilions will become lanterns that glow and shimmer from reflected light off water features in and around the structure and will emit inviting warmth from sculptural features within. There will be serenity and a theatrical quality to these spaces befitting entries to the world's tallest structure.

The exterior of the pavilion will be a full double wall. Heat from the sun will be contained within the two glazed surfaces by sun shading devices that operate to provide pavilion and optimum transparency when no sun is present. The glass is four side silicone glazed with pressure plates at each intersection on both internal and external glazing system. The plates are supported by stainless steel rods that connect to the cable net system running both vertically and horizontally through the interstitial space.

The pavilions are designed as instruments of light.

Figures 10-11. Pavilion at Burj Dubai. © Emaar Properties PJSC
The Architecture of Adrian Smith, p. 231.

Tower Exterior Wall

By contrast, the tower's exterior wall is solid and reflective, shielding sunlight from its interior spaces. It will be a kinetic visual experience reflecting the color of the sky as the sun moves over the building. The design of the façade went through a series of studies, although it was initially presented as a stainless steel and high efficiency low-e double glazed façade with floor to optimum shade to the interior when sun is hitting the ceiling glass to take maximum advantage of its views from great heights. The details of the mullion system were studied using extruded tubes attached by brackets at approximately 450 mm from the glass surface and later developed into wing shaped mullions of polished stainless steel projecting from the glass wall by 225 mm at every 1.2 to 1.5 meters on center throughout the body of the tower. The polished stainless steel vertical fins are shaped to reflect the elements within the tower façade. At the towers base the fins are deeper and the glazing elements are more horizontal in proportion and are fritted with grey line work that will reflect in the polished fins creating a pattern of curved lines when seen obliquely. In the tower the vertical fins also serve to separate adjacent panels of glass and help give the impression that the faceted glass is curved. At the terraces, created by the setbacks, the fins become the structure for the handrails and the light fixtures that will illuminate the tower at night. They will provide a sense of secondary enclosure for units with terraces. The spandrel panels of the tower skin will be stainless steel with a linen texture. This texture is helpful in reducing any distortion in the metallic surface of the flat stainless steel panel.

The reflective glass is designed with a thicker outer lite of glass and a thinner interior lite in order to reduce what is known as a pillowing effect when the pressure of the air in the interstitial space is greater or lesser than the outside air pressure. By using a thicker exterior layer of glass, the interior lite will deflect before the exterior lite, thus maintaining a flatter appearance from the exterior.

Near the outer points of the three wings of the tower the module of the mullions modify and increase in distance until they reach the maximum width of 2.2 meters, thus enhancing the panoramic view from the tip of the tower. This move also establishes a greater density of activity and materiality near the central spine of the tower that dissipates as it moves out towards the end of the tower.

Figure 12. Close-up of tower exterior wall. © Emaar Properties PJSC *The Architecture of Adrian Smith*, p. 242.

At the mechanical levels the use of stainless steel is increased to 70% stainless and 20% glass and 10% open, composed in horizontal ribbons. Added to this texture are 200mm polished stainless steel tubes that become the structure for the window washing equipment. These tubes wrap around the entire mechanical floor and come into the enclosure at the central spine where the window washing rigs are stored.

The exterior skin is typical on all surfaces of the tower above the third floor until it becomes the spire at The which point the density of the verticals increases as the radius of the surfaces decrease in order to reduce the size of each individual piece of glass.

At the very top the spire is solid steel clad in stainless. The primary focus of the design for the exterior wall was to eliminate any horizontal surfaces that could collect the fine grained desert dust and sand, thus reducing the staining that would result from light rains.

Tower Top

The top of the Burj Dubai tower has been the subject of continuous discussion and development. The reason for this is that the initial concept scheme had a greater aspect ratio than the early massing developments after the competition. Compounding this was the desire from some members of the development team to keep the height of the tower down to something in the 550 meter range. This height, they felt would still achieve the desired goal of the worlds tallest building when completed, The problem I had with this was that I couldn't get the tower to look or feel like the competition scheme and the massing schemes that we developed were also not satisfying to Mohammad Alabbar. Throughout the months as we continued to develop the floor plans, the exterior wall, the structure, the life safety systems, the elevatoring systems and mechanical plant, we were working on the massing and the top. Each meeting during this phase with the client we would produce another massing model. Each time we would inch it higher and there would be pressure to reduce it. Finally, after the developer of the palms in Dubai surfaced a concept by I.M. Pei that was significantly taller that the 550 meters limit we were up against, EMAAR allowed us to pursue taller schemes. This was the breakthrough that we needed to get the massing right and to develop a top that was of significant mass to feel like it belonged to the base and middle of the tower and that it could almost complete the stepping system that was developed at the lower levels.

We lived with this scheme for about a year but I was still not satisfied that we had it right and so we kept studying it and as time went on we had what I felt was the top. The next step was to convince Mohammad that this was right. It was no easy task since it meant going back to the wind tunnel test and revising the structural calculations both for acceleration of movement and for foundation strength. We were in the middle of testing piles that had been driven on site at the time. During the last design development meeting for the tower and the first schematic design presentation of the interior design for the residential public spaces and office public spaces, we commissioned a 1:500 scale model in stainless steel with a removable top piece and presented to Mohammad the then current scheme and the new proposed final scheme. He loved the higher and final scheme and directed that it be pursued. That was all we needed to finish the testing and re-engineering of the Tower. As it turned out, the additional mass actually had a dampening effect on the tower, so Bill Baker was happy and so was I and the rest of the design team.

The Interior

The interiors of this project were just as important to the success of the project as the massing. We were finally selected and released to develop a concept for the interior spaces of the residential and office components of the building. Giorgio Armani was to personally direct the interior work for the hotel. Nada Andric has led the interiors effort for the residential public spaces, and Marshall Strabala, the Burj Dubai studio head, has led the effort for the office lobby. Nada felt, as I did I, that the interiors should be an extension of the wavy character of the exterior and proposed a series of spaces that were freeform in nature and of varying heights as one moves through the spaces of the public areas. She also discovered that these forms were embodied in the Arabic alphabet and studied their relationship to find a philosophic response that would connect the two. She enlisted the help of Lonny Israel, a graphic designer from our San Francisco office to develop some pattern ideas for the floors based on the Arabic script. We liked the connection and it gave the interior development a solid connection with the context of Dubai and the tower design. She developed each space with and without the strong use of this idea and we presented both to Mohammed Alabbar in his home.

The office lobby design was a somewhat different challenge since most people coming to this entry would be driving and parking in the adjacent underground garage. Emaar also did not want to drive directly on the water court features that were just outside the office pavilion and so we proposed bringing the automobile traffic to the front door below grade in a sky lighted driveway. We opened up the drop off with a large circular opening to let light down into this space and we entered the office lobby at this level. The development of the lowest level consisted of back light glass walls, landscaping and an escalator system that conveyed occupants to the level at which they would access the elevators to shuttle to the 123 floor sky lobby. At this point there is a concierge/security desk and an undulating glass wall with a card reader system that controls access to the elevator system. An important feature of the office lobby space is the free form ceiling made of wood and bridge system that connects the hotel space above to the upper level of the pavilion structure. This feature continues the organic nature of the project into the office environment much the same way as the curved walls do for the residential entrance and public spaces. This highly sculpted feature becomes a landmark feature that differentiates this pavilion from all others.

Building Statistics

The Burj Dubai is a large scale mixed-use project consisting of approximately 600 luxury condominiums including two spas and meeting facilities, 200 hotel rooms with ballroom and support amenities, 350 hotel condominiums, 50,000 square meters of luxury office space, a grand spa and health club, 7 restaurants, the worlds highest public observatory, three floors for communications, 6 mechanical floors and 3000 parking spaces. The towers gross area is over 300,000 sm above grade with a total of 450,000 sm including below grade levels.

Figure 13. Model shot of Burj Dubai. © Emaar Properties PJSC

The Architecture of Adrian Smith, p. 213.

References

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