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The Preliminary Design Guideline for Tall Building:
Exploration of Planning Factors & Building Factors

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Abstract

Every year new tall buildings are being conceived, designed, and built with new schemes. Thus it is important to explore the factors that affect tall building design. Thus it is important to explore the tall building design factors. The planning and design of tall buildings require different criteria than those that exist in regular size buildings. Tall buildings are uniquely expressed by their structural systems where exterior esthetic and requirements of space drive the form and composition of the structural systems. Therefore the exploration of design factors is the key to achieve optimum building systems. Optimization as mentioned here is associated with the efficiency of the different building systems. To achieve an optimal system, there is a need for an understanding of the factors that affect on overall tall building design such as planning module, building function, lease span, floor-to-floor-height, building height (aspect ratio), structural system, environmental systems.

In this paper a statistical approach will be used and will be based on data collected from the practice through a rigorous survey taken. This information is tabulated and analyzed. The major target of investigation will be lease span related to space requirement in the tall building planning. Factors related to lease spans, such as function, floor-to-floor height, planning module, building height, overall plan dimension, and plan ratio (building geometry), will be looked at carefully. IN conclusion, this approach of optimization can introduce a preliminary design guideline for tall building projects. The purpose of the paper should shed some light on the optimum tall building design criteria.

Keywords: Lease span, Function, Floor-to-floor Height, Planning Module, Building Geometry

1. INTRODUCTION

The tallness of a building cannot be defined in terms of its height or number of floors since the appearance of tallness is a relative matter, which is associated with location, culture, and other factors. According to L.S Beedle, the multi-story building is not defined by its overall height or by the number of stories, but only by the necessity of additional operation and technical measures due to the actual height of the building. And also the tallness of building strongly influence planning, design, and use or a building whose height create different conditions in the design, construction, and use than those that exist in common buildings. (1)

Every year new tall buildings are being conceived, designed, and built with new schemes. Thus it is important to explore the factors that affect tall building design. Historically, the early development of the skyscraper occurred in Chicago, from about 1880 to 1900, where tall building reached around 20 stories. Then the architects and engineers in New York succeed to extend the development of skyscrapers to new height because of favorable soil condition. This early phase of tall building evolution was involved with the development of new technology such as vertical transportation, and availability of structural steel. After that the race for height moved from Chicago to New York, the golden age of the American skyscraper was crowned with the 102-story Empire State Building in 1932. During this period, the concern of New York designers were not in expressing the function or structure of the building since their efforts were toward eclecticism, rather than a new architectural expression. The needs to develop an integrated design approach for tall buildings was recognized by a few architects and engineers when tall buildings began to increase in height in many urban areas after World War II. The planning and design of tall buildings require different criteria than those that exist in regular size buildings. Tall buildings are uniquely expressed by their structural systems where exterior esthetic and requirements of space drive the form and composition of the structural systems. Therefore the exploration of design factors is the key to achieve optimum building systems. Optimization as mentioned here is associated with the efficiency of the different building systems. To achieve an optimal system, there is a need for an understanding of the factors that affect on overall tall building design such as planning module, building function, lease span, floor-to-floor-height, building height (aspect ratio), structural system, environmental systems.

In this paper a statistical approach will be used and will be based on data collected from the practice through a rigorous survey taken. This information is tabulated and analyzed. The area of concern in this investigation will be lease span and factors related to lease spans, such as function, floor-to-floor height, planning module, building height, overall plan dimension, and plan ratio (building geometry), will be looked at carefully. To investigate the optimization of tall building design factors, data from 137 tall buildings was collected and investigated. The investigation resulted in data for 58 buildings or 42% of all buildings collected. These buildings are on the list of the world 100 tallest buildings. Based on the Council on Tall building and Urban Habitat (CTBUH); these buildings are more than 700ft high and/or 1,000,000sq.ft in area. CTBUH data contained the name of the building, its location, its height, number of stories, construction date, function, and building materials. The survey of building in the Chicago area included buildings of more than 1,000,000 sq.ft and 40 stories high. Buildings, such as Inland Steel Building, 860

Lake Shore Apartment and 900 Esplanade Apartment were also included because of their significance in the history of tall buildings in this area. This part of the investigation covered 79 buildings or 58% of all building collected.

The information collected on 137 buildings included 62% that are included on the list of the 100 tallest buildings, 71% on the list of the 50 tallest buildings that are more than 840 ft high, which are presented most economic feasibility.

2. DEFINITION OF DESIGN FACTORS

The shape, height and structural system in the tall building design are more or less dictated by a number of related factors. Probably the most obvious is the limitation imposed by the functional requirement, the size of site and the budget. The building shape is directly influenced by the building function, zoning, and structural system, which are intended to maximize building performance, accommodation of function, siting, and structural serviceability. The building height is limited by zoning, space needs, structural material and constructability.

As above-mentioned several design factors, which impact on an overall tall building design, some of the design factors have some correlation with lease span. Thus there is a need to find out what design factors affect the lease span and in what way. Obviously the most important factor, which can determine the lease span, is a building function because each different function requires a different lease span. Other factors will be verified and explored such as; building height, floor-to-floor height, planning module, and building geometry.

A. Lease Span:

The distance from a fixed interior element, such as the building core to the exterior window wall is designated as the lease span. This dimension is dependent upon the functional space requirement and user type. It is very important consideration for interior planning as well as entire building configurations. Acceptable lease spans are determined by the building's functional need such as office, commercial/retail, hotel, and residential.

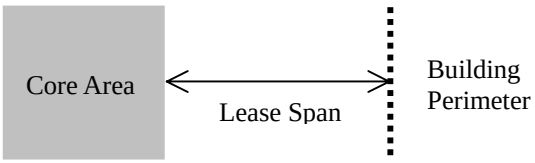


Figure-1, Definition of Lease Span

B. Function

1.Lease Span for Office: In the design of a highrise building for purely office function, the acceptable lease span is range from 10.6M to 13.8M(35 to 45ft) in practice. When considering rentability and flexibility of office planning, it is desirable to have as few columns as possible within the lease span area. A column free floor from window wall to building core would be an optimum solution early development of tall building, the floor-to-floor height for all kind of buildings.

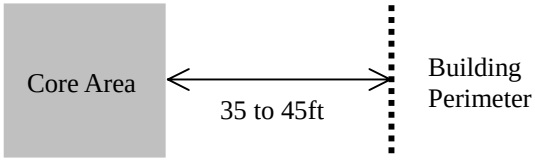


Figure-2, Lease Span for Office

2.Lease Span for Residential; In a high-rise building for only residential functions, the acceptable distance from the perimeter to core range is from 6.1M to 9.2M(20 to 30ft) in practice. The width of the building is limited by the lease span, and since all inhabitable room must have outside exposure that provide natural light and ventilation, this lease span distance is very critical when considering very tall buildings.

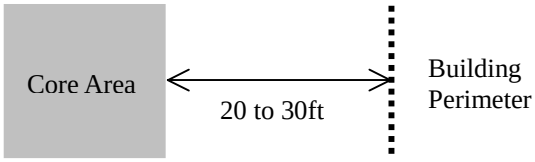


Figure-3, Lease Span for Residential &Hotel

3.Lease Span for Hotel; In the design of a high-rise building for hotel function, the lease span have almost same lease span range of residential function. The depth of hotel typical units including corridor determines the distance from the outside to inside core wall.

4.Commercial/Retail; In multi-use high-rise building, commercial and retail function require longer span than residential and hotel function. These space types are placed below hotel, residential, and office functions. The lease span for commercial and retail space is restricted by upper space function, especially in case of function combined in tower. Thus in this investigation, the primary area of research is office function and residential & hotel function.

C. Floor-to-floor Height

The floor-to-floor height consists of two components; ceiling height and depth of floor structure and space for mechanical/electrical distribution. The overall depth of the floor is crucial, since this also must accommodate the horizontal mechanical/electrical space as well the structure. This depth may be in the range of 0.9 to 1.2M(3 to 4ft) for typical tall office buildings. In residential buildings, the mechanical services are routed vertically consequently the floor depth is much less than that of office. To obtain a reasonable floor depth, construction systems should be investigated for various floor-framing systems. In the design of tall building, floor-to-floor height impacts on the overall building economics. Since a small difference in this dimension can have a great effect on exterior as well as on the structure.(2) It also impacts the structure due to the weight of the exterior wall and wind loads. In fact, I the

was determined by the lese span in order to gain nature

light and ventilation. Owing to the advance of electrical lighting system and mechanical system, the floor-to-floor height mainly should be dictated by the building economic.

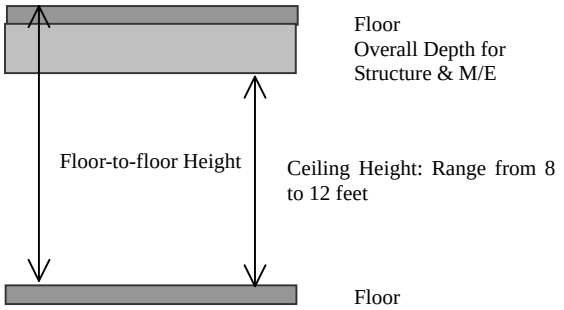


Figure-4, General Diagram for Floor-to-Floor Height

D. Planning Module:

Planning module is a standardized size that can be arranged or fitted together in a variety of ways for space planning. The space allocations are usually based on a consistent space module. The modular approach is most applicable to office (4) and it can be appropriate approaches for space planning of residential and hotel function too. Therefore the planning module and the sizes could be considered in planning of tall building such as 3ft6in(1.1M) module, 4ft by 4ft, 4ft 6in by 4ft 6in, 5ft by 5ft, 6ft by 6ft and more than 6ft 6in module based on previous design guideline. Generally the range between 5ft and 6ft6in are generous for interior planning of office. But in the some of cases, there are less than 4ft 6in module. In residential function, 6ft module or even 7ft module were found.

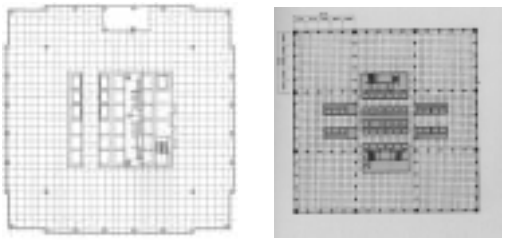


Figure-5, Examples of Office Planning Module

E. Building Geometry(Plan Width to Length Ratio)

The building floor plan is one of the most significant components of the spatial allotments as well as overall structure layout. Geometry holds the building plan together and allows for the partitioning, zoning of space, and structural stiffness. Geometry in its purest form gives us a more sensible solution for tall building design. The tall building can be created as a balance between the geometry figures. The conventional plans are made up of rectangular, square, cruciform, and other linked geometric figures.

There are several geometric samples for tall building plan, which came from existing building condition. That is square, rectangular, triangular, octagonal, circular, and and many tall buildings. In case of triangular, it could illustrated by Central Plaza in Hong Kong, US Steel Building in Pittsburgh, Commerzbank in Germany, and others. Messeturm in Germany and Rialto Building in Sydney

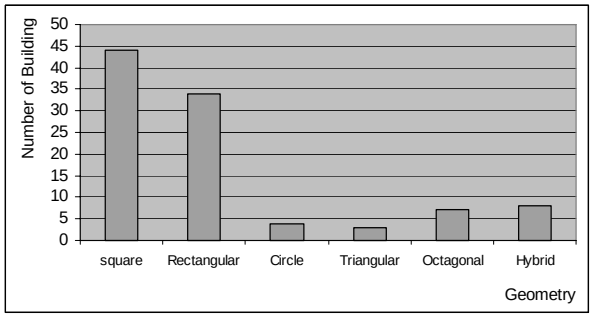
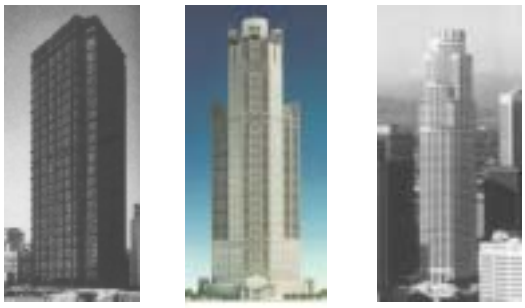


Figure-6, Geometry in Tall Building Plan

hybrid plan is simplified existing building geometric. According to the data based on Council on Tall Building Urban Habitat;100 World's Tallest Building(5), 78% of tall building, which range from 100 highest building has rectangular or square shape in building geometry. In the meantime, there are several different geometric in plan such as circular, triangular, octagonal and hybrid shape in plan geometry. Hybrid shape for building plan usually



based on combined with different geometric; square with circle, which imposed with each other and modification of same geometric or two different geometric. Consequently, the square and rectangular shape of building plan should be major geometric. Examples of square geometry could be illustrated by Sears Tower in Chicago(68.6M by 68.6M/225ft by 225ft), World trade Center in New York(63.7M by 63.7M/209ft by 209ft), Citicorp Center in New York(50.9M by 50.9M/167 ft by 167ft), Bank of China in Hong Kong (51.8M by 51.8M/170ft by 170ft),

Sears Tower Bank of China MLC Tower

Figure-7, Example of Tall Buildings

US Steel 311Wacker First Interstate

were shown the example of octagonal plan geometry. Petronas Tower in Malaysia, First Interstate World Center in L.A and the other buildings showed examples of Hybrid shapes. In fact, the most of tall buildings have rectangular shape in plan geometric such as John Hancock Tower in Chicago, 900 N. Michigan Building, Empire State building, First Canadian Plaza, At & T Building, and many other buildings.

3. OPTIMIZATION OF DESIGN FACTORS

To investigate the optimization of tall building design factors, data of 130 tall buildings, based on Chicago area and some of the significant building in the around world, were collected and investigated very closely. Those buildings are also represented economical building performance based on practical resources. The overall percentages of tall building by function are 21% of residential & hotel, 67% of office, and 12% of mixed-use building based on building data analysis. (According to CTBUH, 18% of mixed-use, 3% of hotel, and 79% of office were shown based on 100 of the World's Tallest Buildings) Optimizing building design aimed to minimize cost, materials, and such without sacrificing functional performances.

A.Lease Span & Function

1. Office Function: According to figure-10, the average of office lease span is 13.5M(44ft4in) and statistically the standard deviation of office function is 9.2, consequently the range of optimum lease span for office function was found to be 10.7M(35ft 2in) between 16.3M(53ft 5in). However some of tall office buildings has been taking more than average office lease span. In these cases, there are obviously the special user needs to allow the longer lease span such as Sears Tower in Chicago:22.8M(75ft) and First Chicago Bank in Chicago:18.3M(60ft).

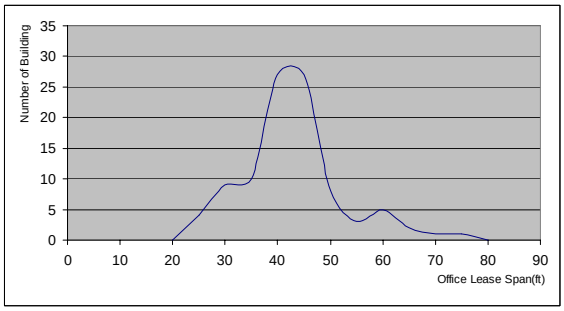
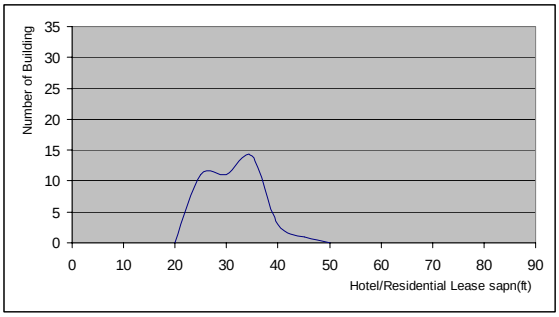


Figure-8, Distribution of Office Lease Span

2. Hotel & Residential Function:

Based on research, see figure-11, the average of residen-

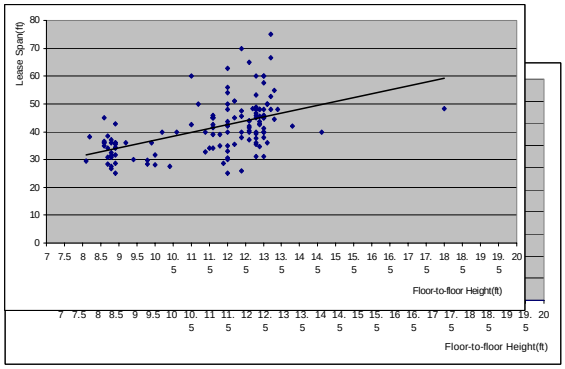


tial & hotel lease span is 10.2M(33ft 6in) and statistically the standard deviation of residential & hotel function is 4.9, thus the range of optimum lease span for
residential & hotel function was found to be 8.7M(28ft 6in) between 11.7M(38ft 4in).

Figure –9, Distribution of Residential & Hotel Lease Span

B.Lease span & Floor-to-floor Height

Based on data, see figure-12, the most common floor-to-floor height for office is range from 3.5 to 4.1M(11ft 6in to 13ft 4in) and the floor-to-floor height for residential and hotel function are ranges from 2.6 to 2.9M(8ft 6in to 9ft 6in). Consequently, the average for floor to floor height should be 3.8M (12ft 5in) for office and 2.7M(9ft) for residential & hotel. However, in the some of the cases, there is more than 4.1M(13ft 6in) some examples indicated 5.5M(18ft) floor-to-floor height. Due to the space requirement and user type, these very high floor-to-floor presented. For example, in Civic center, this building has 18ft(5.5M) high floor-to-floor height because function of this building is court, which require high ceiling interior space. In residential function, the most common floor-to-floor height is range from 2.6 to 2.9M(8ft 6in to 9ft 6in).



Since residential buildings employ the flat plate or flat slab floor system, the residential height has a little bit lower floor-to-floor height than office function

Figure-10, Distribution of Lease Span & Floor-to-floor Height

According to figure-13, as lease span become longer,

Figure-11, Correlation between Lease Span & Floor-to-floor Height

means there is some tendency to increase floor-to-floor height as lease span longer.

C. Planning Module

According to figure-14, the most acceptable planning module should be 1.5 X 1.5M(5ft X 5ft) for office space. It allows for a reasonable variety of office widths at the perimeter beginning with the minimum 2 module office, which is normally 3M(10 ft wide), ranging upward to 4 or 5 module offices, which is normally 6M to 7.6M(20 to 25 ft wide). However some buildings adopted different planning module such as 1.2 X 1.2M(4ft X 4ft) or 1.8 X

1.8M(6ftX6ft) other various module, because every each building have very different space requirement and function. Again, the module of 1.5 X 1.5M (5ft X 5ft) should be most appropriate planning module for office function

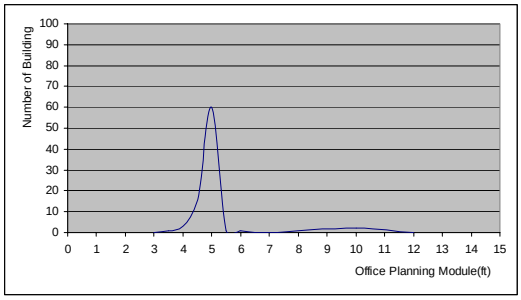
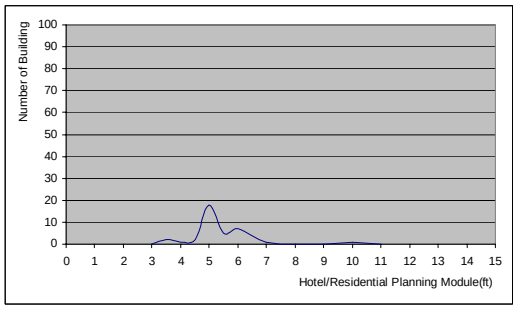


Figure-12, Distribution of Office Planning Module

For residential and hotel, see figure-15, the most appropriate planning module should be 5ft 3in and it is based on room sizing, furniture layout, and lease span. It allows for a reasonable variety of residential & hotel widths at the perimeter beginning with the minimum 2 module room at least 3.2M(10ft 6in wide-wide). However some buildings adopted different planning module such as 3ft 6in(1.1M) or 6ft(1.8M) and other various module, because every each building have very different space requirement, site and marketability. But the 5ft(1.5M) module is most common planning module for residential and hotel.

Figure-13, Distribution of Residential &Hotel Planning Module



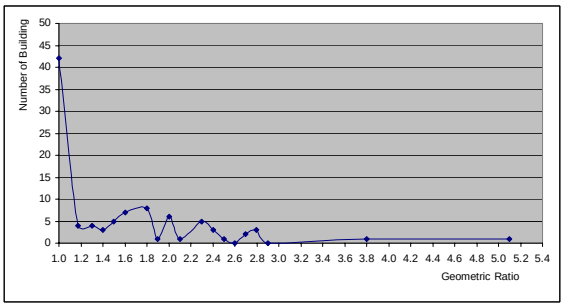
D. Building Geometry: Plan Width to Length Ratio

Square plan has advantages regarding geometric stiffness, core planning and structural behavior. The reason is that, for lateral wind resistance, square geometry offers same stiffness in both directions. Next to the square plan, rectangular plans are most used. Rectangular geometry

building geometric for tall building.

4. CONCLUSION REMARKS

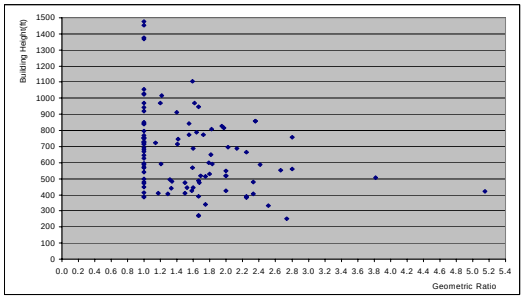
Factors affecting tall building design are not only architectural requirements (building form, floor-to-floor height, lease span, elevator system, planning module), but also



with ratio of width to length close to 1:2, which is usually range between 1.4 and 2.0. Normally as close to the ratio of 2.0, there must be tremendous sail effect on building elevation and the structural efficiency also lower than square plan regarding geometric stiffness; a conventional square plan has 67%, whereas rectangular plan has efficiency range from 43% to 32% (6).

Figure-14, Distribution of Plan Geometric

Therefore One Shell Plaza, in Houston, has a ratio of 1:1.45 rather than 1:2.0 in overall plan dimension. In the early stages, this project was changed from an original 120 feet by 240 feet to 192 feet by 132 feet in plan dimension(7). However the frequency of using rectangular plan is almost 35% thus square and rectangular plan have almost 80% in frequency regarding overall building plan geometry. According to the data analysis, the ratio of width-to-length in plan has tendency having square plan in order to have planning and structural efficiency. Square plan; 1:1 ratio, is the most used plan geometric in tall building. Also the ratio of 1: 2.4 have found in the group of 350ft to 750ft high building whose are having 1: 1.4 to 2.4 geometry ratio, 42% of those building were high-rise residential or hotel. Few building have the ratio of more than 1:2.6, these buildings are most high-rise hotel or residential function. Since residential and hotel require more unit per each floor, these ratio have been found; ratio of 1:1.8 to 1:2.2 has much residential including multi-use tall



building. Obviously the most of high-rise buildings (more than 750 feet high buildings) are close to 1:1 ratio of overall building plan in order to have the structural efficiency. Therefore square plan should be optimal

Figure-15, Correlation Building Height & Plan Ratio

structural constraints (overall building structure system, building efficiency). The selection of an overall tall building system is primarily based on the relationship of architectural planning factors and structural considerations. Among those design parameters, several design factors are explored and analyzed. In particularly lease span and related topics were looked at closely. This approach of optimization can introduce a preliminary design guideline for tall building projects in order to get the economical building performances. In other word, this paper showed several facts; 1.The identification of planning considerations regarding existing tall buildings in order to achieve the exploration of design factors. 2. The presentation of the correlation of design factors in tall building design. 3. The refinement of previously accepted design guidelines.

One purpose of the paper is to shed some light on the optimum tall building design criteria.

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