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Space Efficiency in Multi-Use Tall Building

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Abstract

This paper seeks to make a contribution to the development of the design strategies for multi-use tall buildings in relation to space efficiency of the building for architects, engineers and developers during their early phases of the design process. This research describes the complex challenges of a design development process influenced by vertically stacked functions. This paper addresses the important parameters in the design of multi-use tall buildings and their relationship to the space efficiency. Parameters including functions, lease span, floor-to-floor height, vertical transportation, site area, FAR(Floor Area Ratio), building height, number of floors, building size at the base and top, , aspect ratio, structural system were analyzed. Ten multi-use buildings were carefully surveyed and investigated through specific case studies. To achieve this comparative analysis, a comprehensive data base was established. Based on the results of the case studies, a set of quantitative analysis was performed to show relationship among design factors. This paper will help the decision making process within the initial design stage to increase overall feasibility of multi-use tall building. It will give better understanding of the complexity of multi-use building and recommendations to achieve efficient building design.

Keywords: Architecture; Planning; Multi-Use Building; Space Efficiency

1. Introduction

This research is focused to understand space issues that are generated by stacked functions in multi-use tall building. Even though this type of building has much potential to provide advantages over the single-use building, not many such buildings have been constructed around the world. The main reason for this situation is that multi-use building have been considered as difficult buildings to design efficient space and an efficient structural system.

To become feasible for investment in urban areas, this building type must be an effective solution to solve the space problems generated when dealing with mass amounts of commercial, office, hotel, and residential space. Because space efficiency is closely related to the ratio of functional distribution, which means percentage of functions in a building, combination of function components has to be very carefully analyzed. The ratio of core, resulting from arrangement of functions in a building, must be paid an additional attention to get better space efficiency in the early stages of design. Multi-use tall buildings usually have a more complicated and larger core than a single-use building.

By rearranging the function components, core elements and structural system, the space efficiency can be increased. If the building acquires some areas of additional rentable space through rearrangement of the core elements, the economic benefits over the potential building life can be considerable.

These include, lease span, core planning, vertical transportation, floor-to-floor height and structural system. These are closely related to functional distribution, space efficiency and its structural system. Due to the inter-related functional requirements within a multi-use tall building, one change can affect many other factors that must be considered when developing a project.

In mixed-use building, each function needs their own entrance and special elevator system; sometimes traveling through the entire building in other functional areas. Thus, special attention to vertical transportation is required in the planning and development of multi-use tall building. To gain better performance, elevators and lobbies are generally arranged in a geometric pattern. These patterns and configurations will affect valuable rentable areas, however, some shapes are considered to be more economical than others. Reasonable space programs and space allocation of functional

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components can be made into an efficient core, thus overall space efficiency will be increased.

Types of Multi-Use Tall Building

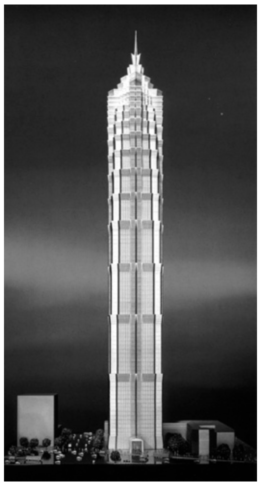
Among the common functional components of multi-use tall building, office, hotel and residential are considered as major functions because of their different architectural and structural requirements. The combinations of these functions usually requires a complex building core and user circulation and these could affect the space efficiency, which means "Net-to-Gross" area ratio.

ultimate flexibility of space division within a very large structural grid. These may be considered more remarkable uses when compared to the usual single use building and multi-use building.

To develop an optimum design, research of each function is necessary. When examining the vertical location of multi-use functions from tenant preference and rentability point of view, below grade should be used for parking, the first level above grade should be commercial use, the next level for office space, the next for hotel and topmost level for residential function. However, from the structural point of view,

a. John Hancock Center
Office + Residential

b. 900 N. Michigan
Office + Hotel + Residential



c. Jinmao building
Office + Hotel

Fig. 1. Type of Multi-use Tall Building

the smallest column space, which is hotel or residential function, always should placed at the bottom of the building for structural efficiency to avoid special consideration in transferring loads. The challenge is to balance these two issues.

Commercial, parking, and an observatory are considered as supplementary functions. There is no or less special architectural planning problem as in the true multi-use tall building but those will give marginal benefits. Multi-use tall buildings can be classified into several types according to their complexity.

- Office with Hotel
- Office with Residential
- Office, Hotel and Residential

Different Aspects of Multi-Use Building over Single-Use Building

In contrast to the single-use building, multi-use tall buildings combine living, working, and servicing activities within the same building. In such cases, commercial, office, hotel, residential, and sometimes parking are included in one building, each function having its own entry and circulation.

From a marketing and economic point of view, a multi-use building has become attractive to developers in the city core. The multi-use building provides the

Space Efficiency in Multi-Use Tall Building

The feasibility of multi-use tall building can be achieved by maximizing the gross and net areas as permitted on the site. To enable the developer and owner to get maximum returns from the high cost of land, the project has to have sufficient functional space to increase land value over the total net rentable space.

The space efficiency is simply referred as ratio of rentable area over the gross area and it depends on the core area of the building. In multi-use building, since the core is generally more complex than these necessary for single-use buildings, rational combination of functional distribution is very important. Distribution of each function will affect the core planning accordingly. Depend on the ratio of distributed function in the building volume; resulting space efficiency will be varying.

2. Methods

Ten multi-use buildings are carefully surveyed and investigated through case studies. Tremendous efforts have required visualizing and computerizing the data to establish digital data base that acquired from various sources. All the measurements are based on acquired architectural drawings however areas measured by center line instead of actual areas. Data showing in this research is prepared only for academic purpose and it could be differ from the published data. The difficulty of collecting data has experienced due to security issues of tall buildings in the U.S after the tragedy of World Trade Center at September 11, 2001.

Format of Case Study

Following are the general categories of the case study.

- Building Description: A narrative story of the building is described such as developer's story, historical back ground issues, information of the site, program of the building and structural system and construction issues.
- General Information: The summary of all information collected from analysis of building. Informations are arranged in a comprehensive table.
- Function and Area Analysis: Areas are carefully calculated and distributed through customized spread sheet by floor, function.
- Vertical Transportation Analysis: Complete survey of elevator system has placed. Number of elevators, floors to serving, zoning, and sky lobby with express shuttle are visualized with floor plan.
- Structural System: Computerized 3D diagrams are produced for comprehensive understanding of the primary lateral force resisting system.

Data Collection

Research items were established in various aspects of the multi-use building through the background research. According to the definition of multi-use tall building described in earlier, all the building data regarding space efficiency and structural system of multi-use tall buildings have been collected for a series of case studies. In order to perform a case study, some of the existing buildings and some of proposed buildings were selected and analyzed

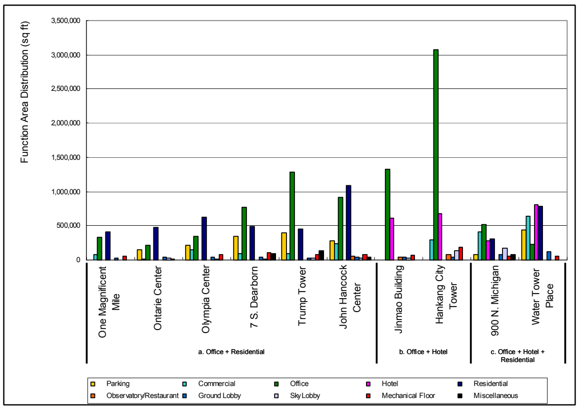


Fig.2. Function Area Distributions

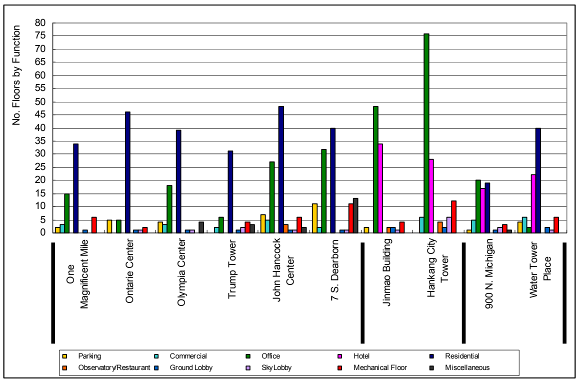


Fig.3. Number of Floors by Functions

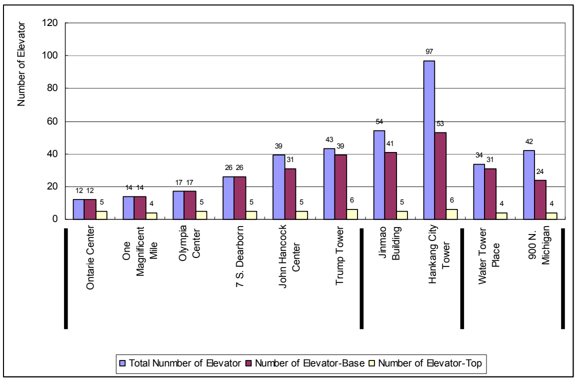


Fig.4. Number of Elevators

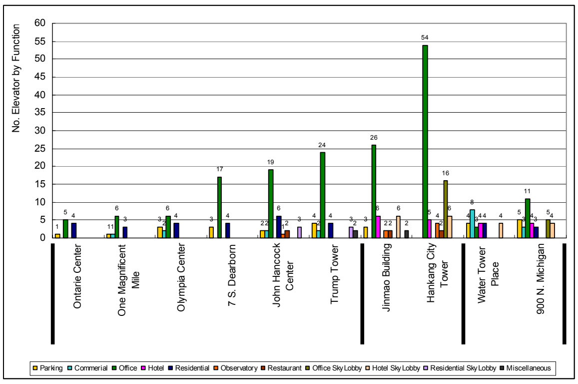
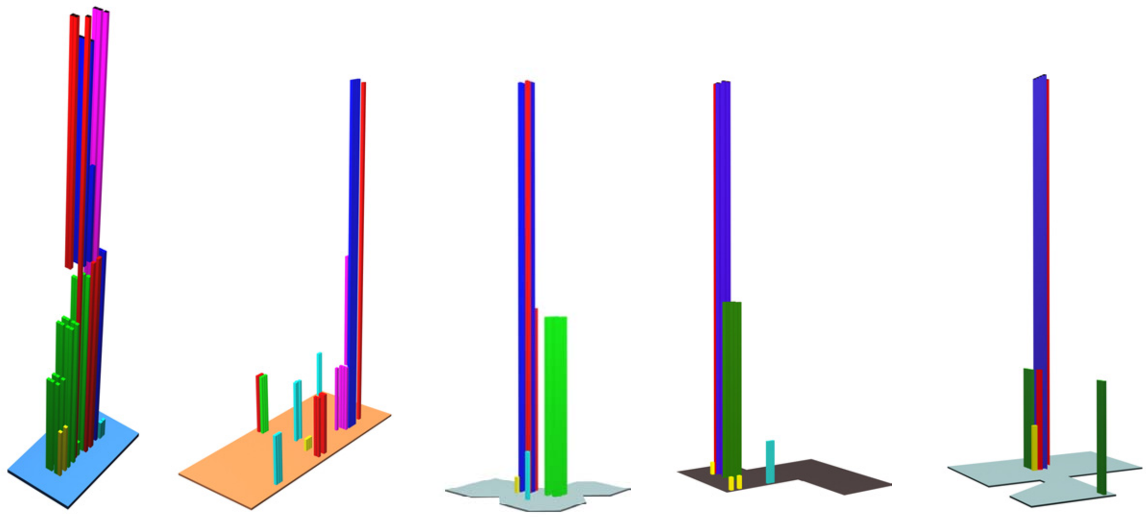


Fig.5. Number of Elevators by Functions



John Hancock Center

Total 39 Elevator

Parking: 2
Commercial: 2
Office: 19
Residential: 6
Observatory: 1
Sky Restaurant: 2

3Express for Residential
4Freight Elevators

Water Tower Place

Total 34 Elevator

Parking: 4
Commercial: 8
Office: 3
Residential: 4
Hotel: 4

3Express for Hotel
7Freight Elevators

One Magnificent Mile

Total 14 Elevator

Parking: 1
Commercial: 1
Office: 6
Residential: 3

3Freight Elevators

Olympia Center

Total 17 Elevator

Parking: 3
Commercial: 2
Office: 6
Residential: 4

2Freight Elevators

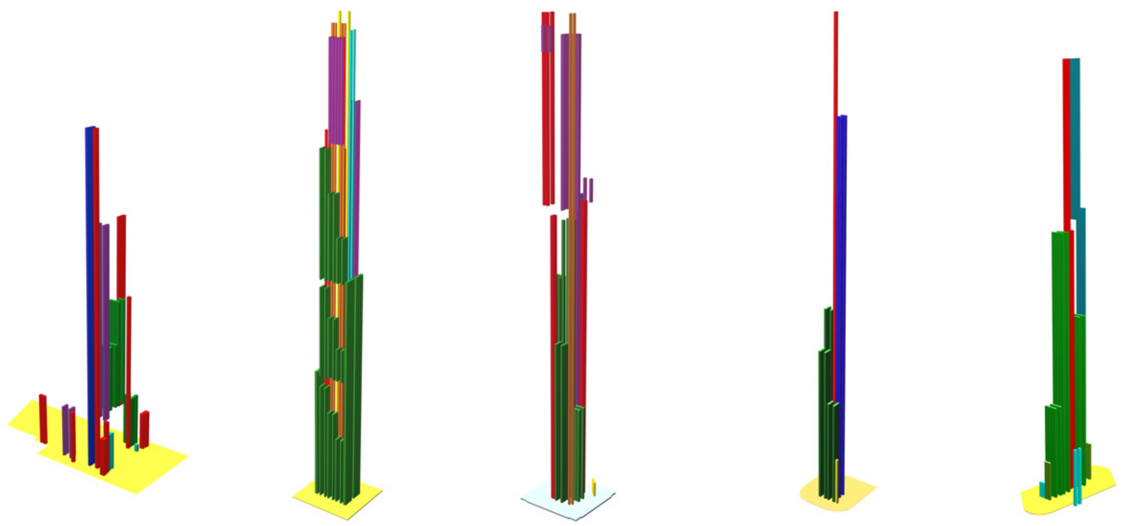
Ontarie Center

Total 12 Elevator

Parking: 1

Office: 5
Residential: 4

2Freight Elevators



900 N. Michigan

Total 42 Elevator

Commercial: 3
Office: 11
Residential: 3
Hotel: 4

5Express for Office
4Express for Hotel
12Freight Elevators

Hankang City Tower

Total 97 Elevator

Office: 54
Hotel: 5
Observatory: 4
Sky Restaurant: 2

2@ 8Express for Office
6Express for Hotel
10Freight Elevators

Jin Mao Building

Total 54 Elevator

Office: 26
Hotel: 6
Observatory: 2

6Express for Hotel

7Freight Elevators

7 S. Dearborn Building

Total 26 Elevator

Parking: 3
Office: 17
Residential: 4

2Freight Elevators

Trump Tower Chicago

Total 43 Elevator

Commercial: 2
Parking: 4
Office: 24
Residential: 4
Health Club: 2

3 Express for Residential

4Freight Elevators

Fig. 6. Analysis of Elevators – Passenger / Freight / Express Shuttle

Inter-related Planning Factors of Multi-Use Tall Building

In the planning stage, many design factors should be carefully studied to achieve comprehensive understanding of a multi-use building. Those factors are usually strongly related to each other, in many cases, one could affect other factors and considerations in many ways.

Fig.2 shows the area distribution of functions in each building.

Multi-use buildings always have two or more dominant functions. In Water Tower Place and 900 N. Michigan, the major functions are equally distributed while the remaining buildings are more oriented to either office or residential. For these two buildings, commercial function is also appearing to be major function. Water Tower Place has three major functions, commercial-21.4%, hotel-26.9%, residential-25.8%, while office function only take 7.3% of gross area.

900 N. Michigan is another example that has more functions instead of one dominant function office-25.7%, hotel-13.9%, residential-15.3%. The percentage of commercial area for this building is approximately 20% which is greater than hotel and residential within a building. Hankang City and Jin Mao Building have a larger area for office space than hotel. They both have office area more than 60% of gross area. One Magnificent Mile and Ontarie Center are more considered as residential dominated building. John Hancock Center has residential area slightly more than office area, residential-39.5% and office-33%.

In a multi-used building, the height of the building is not always well related to the number of floors when compared to a single-use building. Because of its difference between the floor-to-floor heights for each function, the highest building does not always have largest number of floors. The 100 story John Hancock Center is not taller than the 88 story Jin Mao Building. This explains that multi-use building should not be just defined by their height or number of stories, but also by the architectural program and functions of the building.

Fig.3 shows break down by number of floors of each function. John Hancock Center has 27 floors for office and 48 floors for residential. Actual height of 27 office floors is 344 ft and for 48 residential floors is 449 ft.

Fig.4 shows total number of elevators for the buildings, number of elevators at the bottom of the building, and number of elevators at the top of the building. Buildings generally have more numbers of elevators at the bottom of the building but the number decreases, as it gets taller. A building that has tremendous amount of office space such as Hankang City Tower indicates that some functions require more elevators than other functions. If it is an office function, elevators will drop after the office zone and it has ended resulting smaller number of elevators at the upper of the building.

Fig.5 shows Analysis of Elevators by Functions. Office function is displaying larger number of elevator in a building. In John Hancock Center, 19 elevator are assigned for office but, 9 elevators (3 express, 6 local elevators) are assigned for residential although it is larger than office in gross area. (See Fig.2 and Fig. 10)

Special functions such as observatory and sky restaurant required their own elevators. In John Hancock Center, 3 elevators are assigned for only 3 floors (1.7% in gross area) at the top of the building. Hankang City is another example of such kind of building. It has 2 floors for observatory and 2 floors for sky restaurant (also 1.7% in gross area) but these required 2 express elevator for restaurant and 3 express elevator for observatory.

Thus, special considerations should be given when building program includes these functions at the top of the building since elevators have to run though entire building without stopping.

Structural System

For the multi-use tall building, it is important to incorporate the functions located above one another. that accommodates each function without losing its integrity and visual impact. Stacking the structures for different functions requires a complex structural transition to transfer loads from upper portion to the lower one, and that may cause the structure to be less efficient. (See Fig.7) Considering this fact, the balance between the structural efficiency and the functional performance of the building is the primary design criteria for the development of structural system for multi-use tall building. The change in architectural trends and advancement of computer technology in structural engineering enable tall buildings to be more arbitrary and dramatically articulated.(HanSoo Kim, 1997) For the multi-use tall building, it is necessary to reduce the horizontal cross section of a building, causing the upper levels of the building to be narrower than the lower level, to satisfy the functional requirement and reduce the wind load at the upper portion.

Several structural solutions have been developed and are combined to meet a complicated architectural shape for multi-use tall buildings. Office and commercial buildings use longer span, structural floor systems whereas residential buildings use relatively smaller span structural systems.(Kahn and Elnimeiri, 1984)

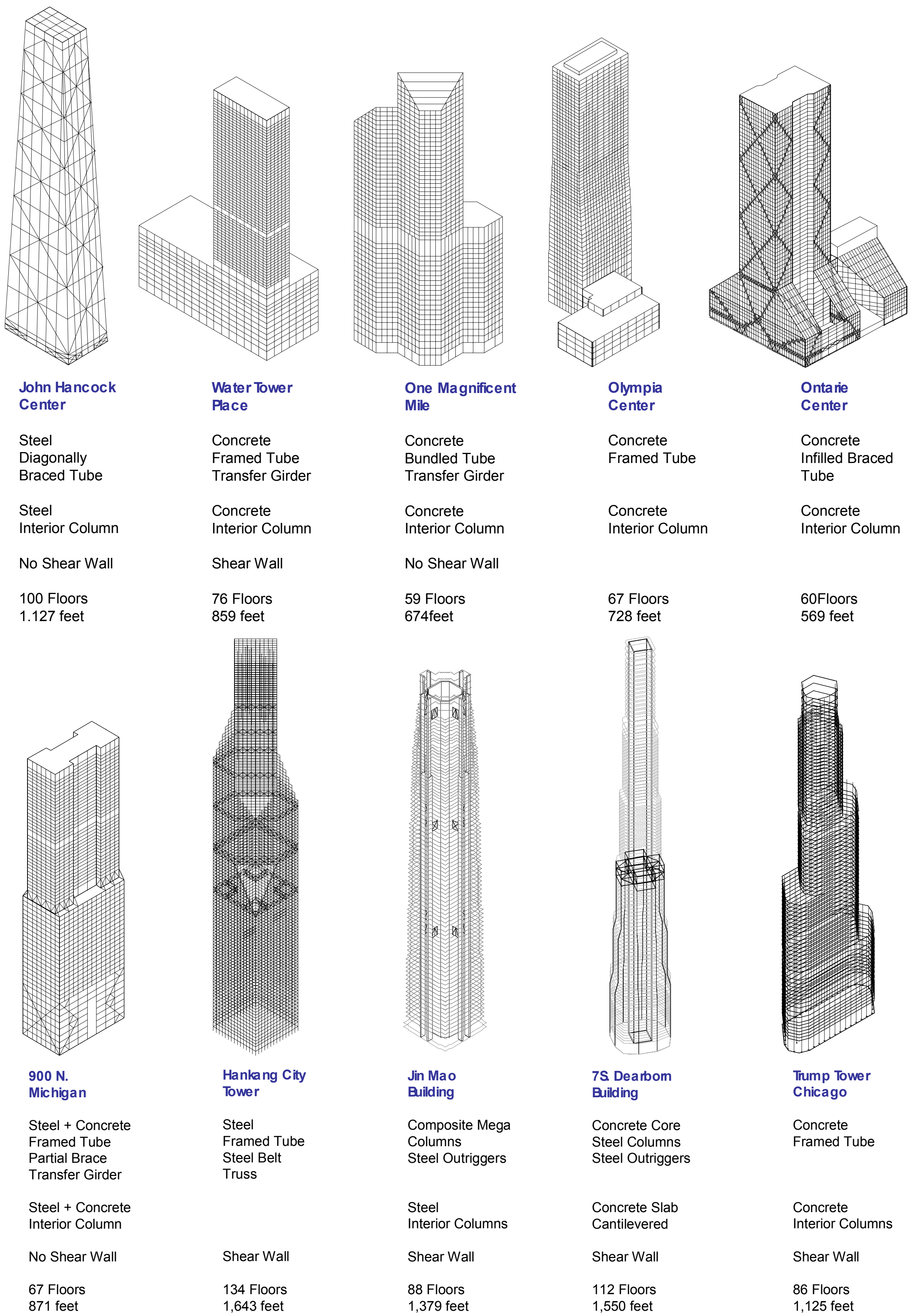


Fig. 7. Structural Materials and Structural system

The relation of space efficiency and gross area, rentable area are shown in Fig.8 When the distance between ◆-Gross Area and ■-Rentable Area is larger, the space efficiency has decreased. When the distances are shorter, figure shows higher space efficiency. Hankang City (G) and Jin Mao Building (H) have approximately 70 percent space efficiency which lower than other buildings.

A greater gross area usually requires more area for service and public space especially in buildings with a larger percentage of office space. Hankang City shows longer distance than Jin Mao Building since it has twice as much gross area although they have identical in space efficiency.

Fig.9 shows relation of space efficiency and number of functions. Theoretically, buildings with more functions are expected to be lower in space efficiency. But, buildings with more functions have also found to achieve higher space efficiency.

This explains that space efficiency is more related with distributions of functions than the number of functions. Buildings with 5 primary functions (John Hancock Center, Water Tower Place, 900 N. Michigan) have shown better space efficiency than some with 4 functions. Hankang City (G) and Jin Mao (H) have more than 60 percent of space dedicated for office which seemed to be main reason for lower space efficiency. Ontarie Center, One Magnificent Mile and Olympia Center, buildings have residential as dominant function showing better efficiency in figure.

Relation of space efficiency and number of elevators has shown in Fig.10 In the figure, Hankang City (G) plotted out of range than other buildings and shows lower space efficiency. Total of 97 elevators mainly resulted from functional reasons. 54 elevators required for office area of 3 million sq ft. Observatory and Sky Restaurant also required 6 additional elevators that go all the way up to the top. (See specific description of vertical transportation in Fig.6: Analysis of Vertical Transportation) This kind of additional feature requires space for vertical transportation and resulted less space efficiency. On the other hands, Ontarie Center has only 12 elevators and results 83 percent of space efficiency. This building only has 206,955 sq ft area which takes 23 percent of office function. It only required 5 passenger elevators.

Fig. 11 shows relation of space efficiency and building height.

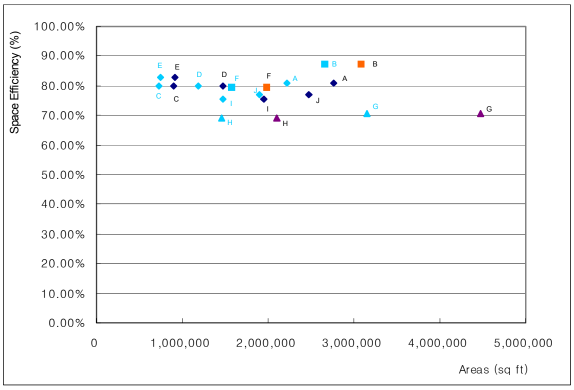


Fig. 8. Relation of Space Efficiency and Areas

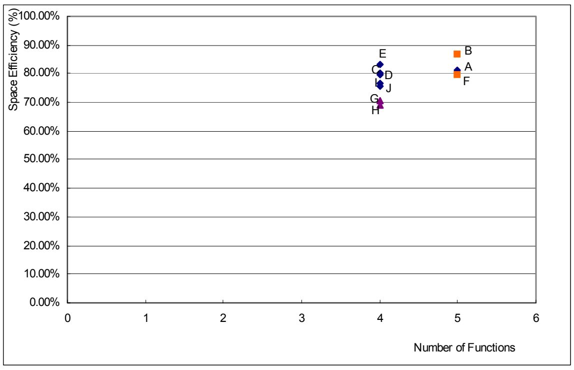


Fig. 9. Relation of Space efficiency and Number of Functions

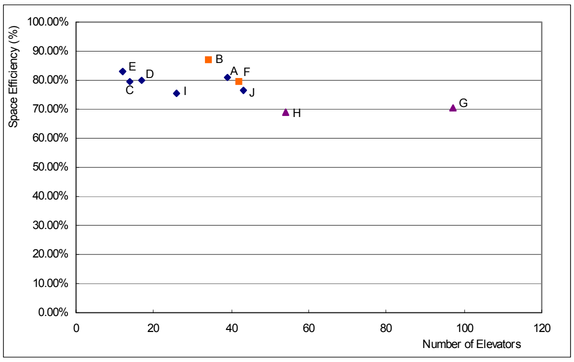


Fig. 10. Relation Space Efficiency and Number of Elevator

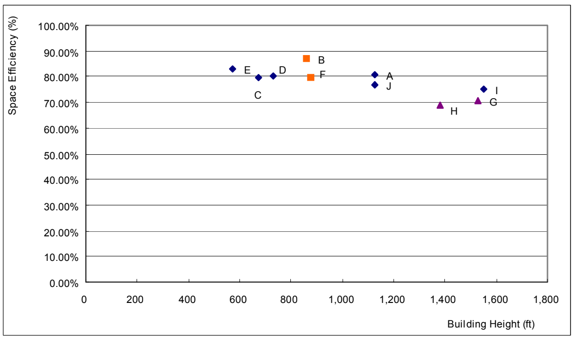


Fig. 11. Relation of Space Efficiency and Building Height

3. Conclusions

This research presents important parameters for the design of multi-use tall buildings and their relationship to the space efficiency. Due to the limited number of existing buildings, the focus of this study cannot be expected to contribute quantitative results. Efforts have been made to present visual analysis that explains the significance of space efficiency and the relations of parameters that impact the space efficiency.

The primary concept is to define the space efficiency as a way to evaluate buildings other than heights of buildings, since multi-use buildings have different architectural and functional organization than single-use buildings.

When we discuss well planned buildings, efficiency is a major issue to be addressed. Space efficiency is just one of the efficiencies such as structural efficiency, construction efficiency, energy efficiency, operational efficiency.

Maybe a well designed building should function well. It should provide a good level of serviceability to the users, and produce maximum profit to developer. These issues are closely related and affect one another. Space efficiency cannot be discussed separate from these parameters.

- Space efficiency is determined by the distribution of functions in multi-use tall building.
- Space efficiency may be lower due to the added gross area that must be dedicated to stacked functions.
- Space efficiency could be lower if building includes special functions at the top of the building.
- In single-use building, space efficiency may be higher than multi-use building.
- Space efficiency could be lower with efforts to improve serviceability
- Space efficiency may be higher if optimum structural systems and resulted building forms are developed together.
- Space efficiency could be higher if building sacrifices the serviceability of building such as reducing number of elevator to have smaller core area.

Space efficiency is only a number resulting from an inter-related decision making process during the early planning and development of the project. A well designed building cannot be determined only by higher space efficiency. When a multi-use building achieves high space efficiency, it has more chance of becoming a good building.

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