PLANNING CONSIDERATIONS OF TALL BUILDINGS:
SERVICE CORE CONFIGURATION AND TYPOLOGIES

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ABSTRACT

PLANNING CONSIDERATIONS OF TALL BUILDINGS: SERVICE CORE CONFIGURATION AND TYPOLOGIES

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In general, tall buildings, some of which are termed as "skyscrapers", are among the typical and almost unavoidable features of the metropolitan cities. There is a competititive race of constructing higher and higher buildings since the birth of the infamous Home Insurance Building in Chicago which is still considered to be the pioneer of the modern tall buildings. Recently, an efficient service core design is strongly needed and inquired with the increase in height and capacity of tall buildings. Such needs and demands are primarily due to the circulation volume of occupants since height has an adverse effect on the size and capacity of the service core. This thesis investigates the features of service cores that play an important role in the planning considerations of tall building design, and their effect on architectural, structural and sustainable design. Within this context, a classification of service cores based on their location in architectural design is proposed.

Keywords: Tall building, high-rise building, skyscraper, architectural planning considerations, service core design, service core configuration, service core types, sustainability.

ÖZ

YÜKSEK BİNALARIN PLANLAMA KRİTERLERİ:
SERVİS ÇEKİRDEĞİ KURULUMU VE SINIFLANDIRILMASI

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Yüksek binalar, zamanla gökdelen olarak nitelendirilmekle birlikte, büyük şehirlerin gelişiminde neredeyse vazgeçilmez bir rol almışlardır. İlk gökdelen olarak kabul edilen Home Insurance Binası'nın inşasından bu yana süregelen daha yükseğe ulaşma tutkusuyla birlikte en yüksek bina inşa etme yarışı başlamıştır. Günümüzde ise, bina yüksekliğinin ve kapasitenin artmasıyla birlikte etkin bir servis çekirdeği tasarımı ihtiyacı ortaya çıkmaktadır. Esas olarak, kullanıcıların dolaşım hacminin artmasının, servis çekirdeğinin boyutu ve kapasitesi üzerinde olumsuz bir etki yarattığı gerçeği göz önüne alındığında, böyle bir gereksinim ortaya çıkmaktadır. Bu çalışma, yüksek bina tasarımındaki planlama kriterlerinde önemli rol oynayan servis çekirdeklerinin özelliklerini ve mimari, yapısal ve sürdürülebilirlik tasarımlarındaki etkilerini incelemeyi amaçlamaktadır. Bu bağlamda, servis çekirdeklerinin mimari tasarımda konumlandırılmaları esasına gore bir sınıflandırılma önerisi yapılmıştır.

Anahtar Kelimeler: Yüksek bina, mimari planlama kriterleri, servis çekirdeği tasarımı, servis çekirdeği kurulumu, servis çekirdeği tipleri, sürdürülebilirlik.

To my parents...

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CHAPTER 1

INTRODUCTION

Tall building design continues to develop, thus attracting greater attention to the service core design that should be integrated into the early stages of the whole design process. The service core, widely recognized as an important building component, is a major challenge particularly for tall buildings due to its complexity, and thus requires a comprehensive attention and investigation. The investigation of the general planning considerations of tall buildings is the framework of this study, in which the service core location and typologies are the underlying concerns. This chapter presents an overview of the general procedure followed in its conduct and concludes with a section covering disposition that serves as a guide throughout the remaining part of the study.

1.1 Background

The service core is an increasingly important aspect of tall buildings, which is fundamental to their development and operational effectiveness. The service core requires a different design approach, typically demanding a higher level of integration of services than in other building types, and hence, it is often regarded by architects as a technical component of design, which has to be controlled by technical experts such as structural and mechanical engineers. It is noteworthy that the service core design is a supplementary to, and yet a starting point of, the architectural design process, for it incorporates all the functional properties related to services as well as vertical circulation and affects the architectural planning decisions. For this reason, architects should be fully aware of the importance of the service core not only because it is a technical component of the building but also because it is an inseparable part of the architectural design process, which needs to be considered at the initial design phase.

Tall building typology requires an interactive, multi-disciplinary and a comprehensive approach that seeks an efficient design for the service core from the early phases of the whole design process. As the height increases, service core becomes a challenge for the designer mainly because tall buildings are required to be more efficient in terms of space use than any other building type. This is primarily due to the adverse effect of height on usable space as service core expands to satisfy the requirements of vertical circulation, and in some cases, resistance to lateral loads.

In regard of sustainability of design, the service core is also important basically because it is considered as one of the factors determining the level of sustainability achieved throughout the building, for it is responsible for a major share of the energy consumption. Furthermore, as building height increases, so does the construction cost of service core, accounting for a large portion of the total building cost due to its large scale. Thus, it has great importance for the investors who conceive such buildings primarily as products to generate a feasible financial return. In tall buildings where sophisticated service systems are involved, service core must be arranged with the greatest level of compactness and efficiency possible due to its substantial space allocation within the building. Hence, the role of service core, while always present and instrumental in the design process, becomes all the more crucial in the design of tall buildings.

As outlined above, the design of service core has become a major concern in tall building design. It is, however, a complex issue and has numerous determinants to be considered. The present study provides a far more comprehensive approach to the service core, where the design considerations are threefold: architectural, structural and sustainability. This thesis argues that the service core in tall buildings cannot be designed outside of this framework and all components should be considered during the design process. Currently, several research focus on service core on account of its diverse planimetric configuration. It is hoped that this thesis contributes to the current research by presenting an introduction to the study of planning considerations in the architectural design of tall buildings, particularly service cores and their classification from the architectural point of view. An optimized service core configuration in tall building design is proposed in this research based on the above mentioned factors.

1.2 Aim and Objectives

The study discusses the role of the service core in the development of tall building design and its significance as a consideration at the early stages of the design process. In this study, the main approach to designing of tall building- highly serviced building whose function is dependent on the service core- is to analyze the implications of different configurations for the service core within the floor plate. In order to study the characteristics of each of these aspects and their consequences, a classification has been developed in this thesis. This classification permits, for research and design purposes, the isolation of one or several aspects at a time by idealizing the characteristics of others through the use of simplifying assumptions.

The primary objective of this study is to provide architects the notion that service core is not only related to technical aspects of the tall building, but also an important architectural element that determines the overall concept of the building. This study is concerned with the general characteristics of service core design, which is perceived as an architectural attitude rather than a technical aspect. Therefore, it does not cover the issue of service core in the technical process of the building as a mechanical/electrical design methodology which requires more field-specific theoretical studies. Rather, it aims to increase designers' awareness of current service core design practices and make them consciously think about service core design in the conceptual design phase of tall buildings. Overall, this study is expected to enhance the understanding of how to apply and extend the established design theory and design methodology for the service core in order to improve the design guidance for tall buildings.

1.3 Procedure

The service core design for a tall building involves a systemic approach that enables the designer to analyze all of the building's components as a whole, thus entails an interdisciplinary analysis of architectural, structural and sustainable design considerations. For this reason, all these parameters have to be defined clearly. Thus, in particular, planning considerations in the architectural design of tall buildings including planning modulation, lease span, building function, floor-to-floor height, service core, and structural system are presented. Following a brief analysis on the planning considerations of tall buildings, the study focuses on the service core design which involves the definition, function and elements as well as the general characteristics of the service core.

Different architects have various approaches to the design of service core; therefore in order to understand these redefinitions/reconfigurations in architectural design, it is necessary to review the current design theories and methodologies. For this reason, as part of the literature research, this thesis presents a categorization of service cores to form a background. This is done by classifying the different approaches towards service core configuration and reviewing the literature; moreover a selection of buildings is analysed to further illustrate the service core design. These criteria form the basis of the development of the service core classification proposed in the following sections. Finally, the proposed classification is related to the case study examples by reviewing the projects with special emphasis on their service core configurations.

1.4 Disposition

The study consists of five chapters, the first of which is this introductory chapter.

Chapter 2 elaborates on the concept of tall buildings, including the definition, emergence and historical background, together with a historical overview of the evolution of service cores.

In chapter 3, architectural design considerations of tall buildings are summarized to provide for a general understanding of tall building design.

Chapter 4 overviews the basic considerations in the design of service core and presents a conceptual classification for the service core configuration proposed by the author.

In chapter 5, the conclusion and the results of the study are given, together with a discussion of these in terms of its objectives and the relevant aspects iterated in the literature. Some recommendations for future researchers are also offered, herein.

CHAPTER 2

HISTORICAL OVERVIEW AND DEFINITIONS

As a new building typology that emerged in the late nineteenth century, the tall building represents a growing and increasingly important part of the urban civilization that mankind has developed over more than a century. In this context, this chapter offers an overview of the development of the tall building as a unique building type. In order to achieve an understanding of tall building development, the chapter first reviews social and technological developments and transformations in human society from the nineteenth century to the twentieth century in a way that resulted in the construction of ever taller buildings. Following this, the different definitions of the tall building which vary on the basis of the specificity of each discipline are discussed. Finally, the development of the service core is presented as a critical building component, which is important for the design of tall buildings and in particular to the concern of this thesis.

2.1 Historical Development of the Tall Building

The aspiration to create increasingly taller structures dates back to ancient times as is evident on certain structures and forms such as the Tower of Babel, Colossus of Rhodes, the pyramids of Egypt, Mayan temples of Mexico, the Kutub Minar of India. As a powerful expression of human ingenuity, such monumental structures represent human’s desire to reach God and act as the most important symbols of power. From ancient tall structures to the modern skyscrapers, humankind has achieved greater heights, pushing the limits of technology as demonstrative of the mastery of civilization and control over the environment.

The main evolutionary change of the tall building is in its function, from some religious symbols to a commercial concept that has become acceptable as an expression of urban civilization. The growth in modern tall building construction, which began in the late nineteenth century, is intended largely for commercial purposes. While human ego and monumentality were the prime motivations behind the construction of ancient towers, contemporary tall buildings are primarily a response to the scarcity and high cost of land resulting from a concentrated population growth in major cities. Growth in population and economic resources along with limited building sites and infrastructure in centralized business districts have given rise to the construction of tall buildings in major urban centers**.** As countries become industrialized**,** tall buildings are required to consolidate people and services in order to respond to the demand by commercial activities in central business districts**.** As a consequence of the economical growth in the late nineteenth century, the demand for tall buildings increased as corporations recognized the advantages of agglomeration and prestige with imposing tall office buildings. Thus, increasing the building heights was the logical consequence of the enormous pressure on the building sector as a result of rapid population growth, lack of space and speculation.

Technological development was the major factor that underlined the emergence of tall buildings in the nineteenth century. The progressive technology and industrialization responded to the necessities of the tall building development with new construction systems. Practically, the evolution of tall buildings could not have been possible without the two major technical innovations that occurred in the middle of that century, namely the steel-frame technology and the invention of the elevator. The development of structural systems from conventional load-bearing masonry structures to the frame systems combined with the invention of a safe passenger elevator by Otis in 1854 contributed to the evolution of tall buildings. Additionally, continual improvements to these technologies such as fire protection systems, mechanical and ventilation systems removed the basic limitations regarding the height of buildings. Consequently, with the advent of new technology, tall building construction is considered as a practical solution in all senses including space and economy for housing problems of big cities.

As the construction systems became more efficient and sophisticated, the architectural profession also changed in response to the demands of society with new technological possibilities. In this context, architects began developing new solutions that incorporates social and economical factors to develop an appropriate and optimum design. The development of new construction methods together with the new materials has enabled architects to develop new forms of expression and to reach greater heights. Such changes in the form and organization of buildings were necessitated by the emerging architectural trends in design in conjunction with the demands of society and technological developments. Consequently, the necessity of a different type of building has directed architects to explore the potentiality of the tall building as a powerful expression of architecture that respond to the demands of the modern civilization.

The invention of new materials and the increasing level of construction technology in the nineteenth century have enabled the development of tall buildings that are both efficient and resistant. Particularly, with the invention of iron and steel in the late-nineteenth century, architects and engineers began experimenting with new ways of using iron and steel. Prior to such improvements in the construction field, design of structural systems for tall buildings was done in a conventional way that includes the incorporation of massive load-bearing walls as part of the masonry construction. The last building to use this design was the 17-story and 64 m high *Monadnock Building*, which was constructed in Chicago in 1891 (Figure 2.1). However, the need for very thick walls to support the building's weight due to the limitations of masonry construction resulted in a decrease in the floor area. Finally, technology responded to such challenges of masonry construction with the development of high strength and structurally more efficient materials like wrought iron and then subsequently steel. The contribution of these new materials in relation to the development of tall buildings was that the employment of iron in construction resulted in a change in the traditional rules of masonry and thus, along with steel, gave way to the proliferation of tall buildings. One of the earliest examples was the 12-story Home Insurance Building (1885), which was designed by William LeBaron Jenney in Chicago. Incorporating a combination of steel and iron skeleton frame, the Home Insurance Building is considered the first building to employ steel skeleton construction and embody the general characteristics of a modern skyscraper (Figure 2.2).

Figure 2.1 Monadnock Building   Figure 2.2 Home Insurance Building

Continual improvements to these technologies after their introduction in the late 19th century permitted building construction to greater heights. Along with the steel skeletal structure as well as consequent glass curtain wall systems, new systems such as mechanical ventilation, lighting and heating were introduced to help to further increase building heights as well as enhancing the comfort standards. This process, in conjunction with an expansion of commercial activity in centralized business districts, led to a clustering of tall office construction in the cities of Chicago and New York. This new generation of tall buildings culminated with the construction of the 319 m tall Chrysler Building in New York in 1930 (Figure 2.3), immediately followed by the 381 m tall Empire State Building in 1931, which held the record as the world's tallest building for 41 years (Figure 2.4).

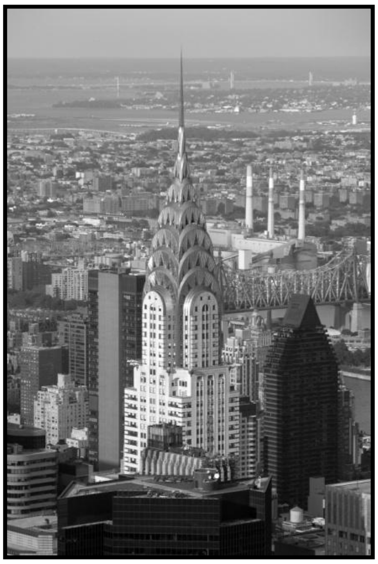


Figure 2.3 Chrysler Building,
New York, 1930

Figure 2.4 Empire State Building,
New York, 1931

The years following the 1950s revealed even greater advances in technical knowledge and more creative solutions regarding structural systems for tall buildings. Departing from the frame structures, a significant evolution occurred with the development of tubular structures in the late 1960s. This transition of structural systems from rigid frame to tubular systems enabled tall buildings to reach greater heights such as the World Trade Center (417m) (Figure 2.5) the Sears Tower (443m) (Figure 2.6), the John Hancock Center (344m) (Figure 2.7) and the Petronas Towers (452m) (Figure 2.8), each of which was noted for its innovative structural system. Since then, tall buildings have evolved toward taller with the development of more efficient systems in conjunction with the changes of the design trends and architectural movements. Although most of the early tallest buildings were built in the United States, now over half of the tall buildings in the world are constructed in various cities across the world, outside of North America.

Figure 2.5 World Trade Centre, New York, 1972

Figure 2.6 Sears Tower, Chicago, 1974

Figure 2.7 John Hancock Center, Chicago, 1970

Figure 2.8 Petronas Towers, Kuala Lumpur, 1996

Consequently, tall buildings have become unavoidable due to the scarcity of land in urban centers, high land cost, economic prosperity and technological innovations at the end of nineteenth and early twentieth century. Early tall buildings were the outcome of the insufficiency as well as the high cost of land in metropolitan cities, particularly in New York and Chicago, but today, they are mostly for the symbols of the cities and pride of nations by representing prestige and power.

2.2 Definition of Tall Building

Given the multifarious history of the tall building and given the fact that it is an architectural phenomenon determined equally by technological development**,** design-conceptual change and social transformation, defining the ‘tall building’ is difficult in specific terms related to size. There is no consensus on what constitutes a tall building as a particular building type since the outward appearance of tallness is a relative matter depending on time and place. As an assertive term describing a very tall building, ‘skyscraper’ refers to a specialized building type that primarily takes into consideration its non-conformity and particular relation to its surroundings and the environment. However, the terms ‘tall building’ and ‘high-rise building’ often are associated with the concern of contextual conditions. Hence, the definition of ‘skyscraper’ is based on the perception at the time while the terms ‘tall building’ and ‘high-rise building’ are better defined in contextual conditions.

The human aspiration towards constructing higher is not a new phenomenon, as traces of this urge exists in numerous historical examples, such as Great Pyramids in Egypt or Gothic cathedrals in Western Europe (Abel, 2003). While tall buildings gained acceptance for a wide range of uses from the beginning of civilization, the emergence of ‘high-rise building’ as a building type can be traced back to the late 19th century. On the other hand, as a relatively new phenomenon, the term ‘skyscraper’ first appeared in the United States in 1884, with the construction of the “Home Insurance Building” in Chicago. Being the first to contain features that characterized later skyscrapers, William Le Baron Jenney’s “Home Insurance Building” is considered to be the father of the skyscrapers. The notion of tallness has been changing over time, according to the desires of society and the technology as well. However, in spite of different understanding and definitions, the terms ‘tall building’, ‘high-rise building’, and ‘skyscraper’ have common characteristics regarding the notion of tallness. All these terms have been applied to the buildings which are exceptionally tall; and they all have become acceptable with the changing of modern society and culture driven by technological evolution.

Much intellectual effort in many academic disciplines has been devoted to defining the ‘tall building’; therefore, the dividing line may be drawn by various concepts from the field of architecture into the field of structural design. From the point of architectural design, a building can be considered as ‘tall’ when its design or planning is influenced by its tallness. Council of Tall Buildings and Urban Habitat (1995) offers a general definition, stating that “it is a building in which tallness strongly influences planning, design and use, and it is a building whose height creates different conditions in the design, construction and operation from those that exist in common buildings of a certain region and period".

From the structural design point of view, Taranath (1988) defines a building tall when its structural analyses and design are in some way affected by the lateral loads, particularly sway. As building heights increase, the forces of nature become the primary concerns affecting the structural system. In the most general sense, Schueller (1986) defines a tall building as the building which must cope with the vertical forces of gravity and the horizontal forces of wind above ground and the seismic forces below ground. Thus, a building is considered as tall for a structural engineer, when the building has to be sufficiently economical to resist the forces of nature, particularly lateral forces due to wind and earthquakes.

Physically, Ali and Armstrong (1995) define the tall building as “a multistory building generally constructed using a structural frame, provided with high-speed elevators, and combining extraordinary height with ordinary room spaces such as could be found in low buildings”. In aggregate, the authors define such buildings as “a physical, economic, and technological expression of the city’s power base, representing its private and public investments.” According to Beedle (1971), tall building is defined by “the necessity of additional operation and technical measures due to the actual height of the building”.

As a consequence of the specificity of each discipline, the definition of tall building requires multidisciplinary involvement. Thus, due to the interdisciplinary nature of tall building design, many factors must be taken into consideration when defining the tall building. As is obvious from the definitions provided above, definition of such buildings is controlled by a number of criteria; some are related to its environment and perception of the people, and others related to structural as well as technological considerations such as elevators or fire-safety requirements. In his recent research "The skyscraper: Epitome of Human Aspirations" Ali (2005) indicates that tall buildings are perceived by people in different ways. As such, they are viewed by the architect who designs them, the contractor who builds them, the engineer who designs them, the corporation that finances them and the neighborhood in which they exist—all from their own viewpoints.

As previously emphasized, there is no consensus on what constitutes a tall building as a particular building type since the height varies with the changing technology and the desires of society. It is, first of all, explained by the absence of common and generally accepted international criteria on whose basis it would be possible to define the tall building by its height and number of stories. However, in order to understand the meaning of 'tallness' as it relates to buildings, it is necessary to determine 'height limit' above which buildings could be referred to as 'tall buildings'. The official Council of Tall Buildings and Urban Habitat (CTBUH) criterion for measuring the height of tall building is from the level of the lowest, significant, open-air, pedestrian entrance to the architectural top of the building; not including the antennae or flag poles. In this context, the building with at least 14 storeys or 50 meters in height is defined as a 'tall building' and the building over 300 meters in height is defined as a 'super-tall building'. On the other hand, the Emporis Standards Committee defines a 'high-rise building' as a building with at least 12 floors or 35 meters in height and a 'skyscraper' as a building whose architectural height is at least 100 meters (Emporis Data Standards ESN 18727, ESN 24419).

In this study, due to the fact that the buildings that exceeds 40 storey necessitates the implementation of high technology by means of special structural systems and aerodynamic design due to their vertical development, the word 'super-tall building' is used for those buildings having more than 40 storey.

2.3 Historical Development of the Service Core

Similar to the tall building typology, the present context of the service core is the result of an evolutionary design process; and it is useful for the designer to be aware of this process together with the historical precedents and factors. This section presents the development of the service core which is an inseperable part of the tall building historical development.

2.3.1 Early Years of the Service Core

The concept of a compact and defined service core did not exist for the very first examples of tall building typology in the late 19th century, particularly in New York and Chicago, where they developed. The layout of such buildings mainly depended on the ability of the tall building to receive natural light for workspaces and commercial value of space; which resulted in locating the elevator shafts, stairs and other service shafts on the dark and commercially less valuable spaces. All these factors led to the central arrangement of the core, which was also considered as advantegous in terms of accessibility, especially in cases of multiple tenancies.

In New York, the layout of the building was determined by the shape and size of the lots which were interpreted by architects in two different organizational schemes (Trabucco, 2010). The first type designed the buildings on almost square-shaped parcels with the services located in a central position together with the provision of circulation by way of a perimeter corridor that encircles the core. The second type varied remarkably in buildings that occupied the entire depth of a city block. In this case, the elevator shafts, sometimes 12 to 14 in number were arranged in a single row in the centre of the building (Figure 2.9).

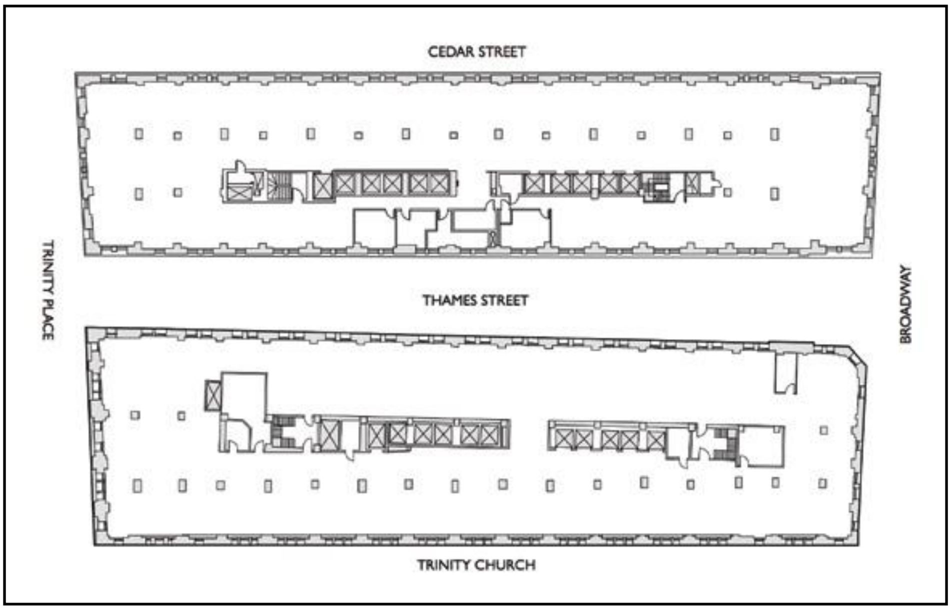


Figure 2.9 The Trinity (top) and US Realty (bottom) Buildings have a long row of elevator and service shafts placed in centre *(Image Source: Trabucco, 2010)*

In Chicago, the grid on which the city was planned was formed of large, almost square blocks about 100 m x 100 m wide, which enables constructing buildings larger in plan (Trabucco, 2010). In addition, the limitation of height by regulations resulted in buildings that were generally constructed massive in plan. The most efficient solution for such a condition was to have a central atrium court in order to allow natural lighting for offices, organizing in two concentric rings. The elevator shafts in this case could not assume a distinct central position and were placed together at one side to serve an adjacent building in the event of expansion on the inner lot line. The staircases were placed at the corners of the inner ring offices and hence, the layout creates a division between staircases and elevators (Figure 2.10). Additionally, during this first period of the era of tall buildings, the service core had little structural relevance since the massive shape of the building required less structural resistance to withstand the lateral forces.

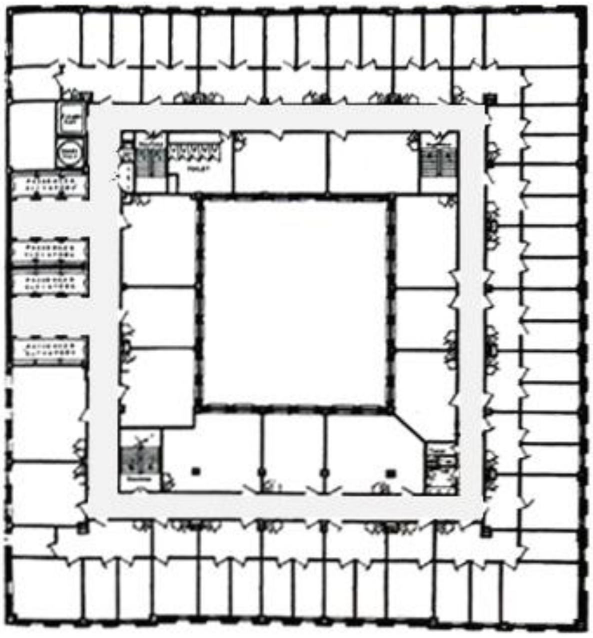
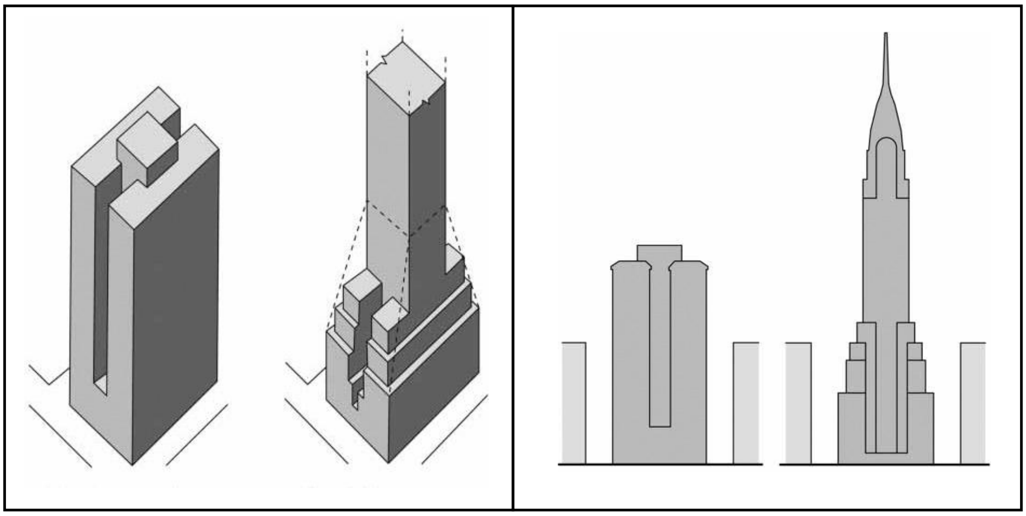


Figure 2.10 The Straus Building in Chicago shows a typical distribution of Quarter Block Building *(Image Source: Trabucco, 2010)*

2.3.2 The Zoning Law of 1916

The lack of planning legislation for the massive buildings of the time had allowed the number and size of such buildings to increase steadily, blocking sunlight from streets and other buildings. In response, the New York City authorities developed the Zoning Law of 1916 in order to limit the volume of these buildings by specifying setback criteria according to height. According to this regulation, twenty five percent of the plot area was allowed to be developed without any height restriction, which resulted in emerging the famous ‘wedding cake’ prototype of tall buildings in New York (Oldfield et al, 2008). The ‘Empire State’ and ‘Chrysler’ buildings in New York are the two famous examples of this prototype. In such buildings, as a consequence of their pyramidal forms, the deep dark central space was occupied by the elevator shafts and other mechanical ducts, forming a single core.

In the case of very tall towers, the service core was placed in the centre while towers built on smaller lot dimensions had cores on one side as its central location would have created offices too narrow to be efficiently exploited (Trabucco, 2010). Along with the limited progress in lighting technology, the service core location was still influenced by lighting limitations and effective space utilisation which was ultimately related to commercial value of property (Figure 2.11).

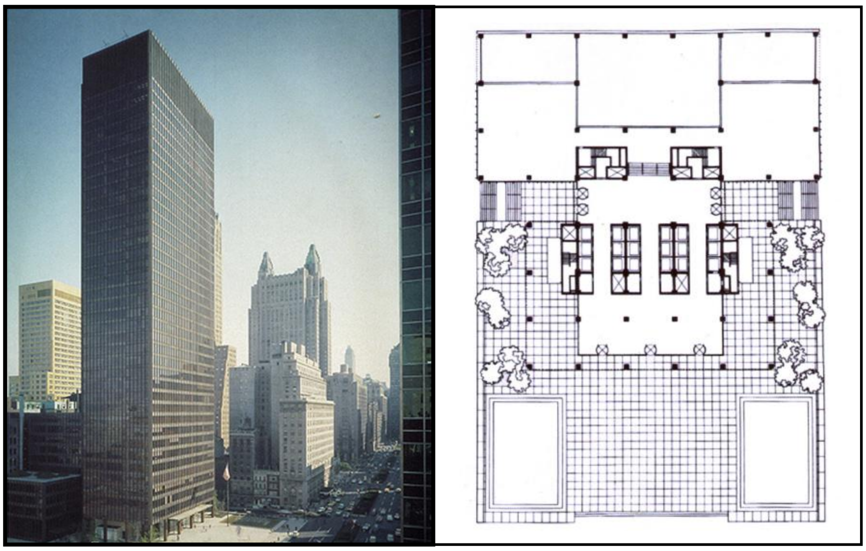


(a) (b)

Figure 2.11 Pre-Zoning Law (left) and Post-Zoning Law (right) buildings in New York, (a) Axonometric view; (b) Elevation (*Image Source: Oldfield et al, 2008)*

2.3.3 The International Style

In the 1950s, tall buildings constructed after the Zoning Law was accompanied by a change in approach to their design due to the advances in technology and the changes in architectural ideology. For many of the buildings of this era took the form of simple geometrical shapes and were designed as to fit in anywhere in the world with little or absolutely no regard of the site and climatic context, reflecting the "international style". Such buildings have experienced massive refurbishments to improve lighting, enhance facade and glazing performance and introduce mechanical space conditioning (Oldfield et al,2008). In particular, the introduction of glass curtain walls to maximise views outside resulted in locating the structural bracing system and service core towards the centre of the building (Trabucco, 2010). The requirement of increased mechanical systems also led to a significant increase in sizes of ventilation shafts which were then eventually combined with the central elevator and staircase shafts to form a compact and solid central core. Consequently, in this era, the service core assumed its characteristic central position as a structural member resisting lateral loads. The Seagram building, built in 1957 in New York City, is one of the typical examples of this movement (Figure 2.12).



(a) (b)

Figure 2.12 Seagram Building, New York, 1957. (a) General view; (b) Plan (Image Source: www.moma.org)

2.3.4 New Generation of Service Core Design

In recent years, there has been a growing number of tall building design that aims to use less resources and reduce the energy consumption since the amount of energy these buildings required became a major issue after the energy crisis of 1970s. In response to this new attitude towards energy, the service core gained an additional value- a new wave of innovations to service core design has become related to sustainability issues. The architects such as Ken Yeang and Norman Foster have been the forefront of such innovative development by displacing the service core from its traditional central position to the exterior of the building for shading, natural ventilation and thermal buffering effect (Trabucco, 2010). As an earlier example of this trend, One Bush Street building in San Francisco reflects these new environmentally conscious principles (Figure 2.13). Poly International Plaza in

Guangzhou, China, developed by SOM Architects is one of the recent cases for this trend (Figure 2.14).

Figure 2.13 One Bush Street, San Francisco

Figure 2.14 Poly International Plaza, Guangzhou

As a result, service cores have changed dramatically as a result of remarkable changes of attitude in planning and design issues. In his recent research on the historical evolution of the service core, Trabucco (2010), mentioning basic historical events in describing these changes, states that the classic configuration in most tall buildings was to have the service core in the central position due to the quest for achieving greater commercial value for the rentable space, technological limitations in artificial lighting equipments and sometimes structural ramifications. However, the author indicates that the challenge of designing an efficient service core has considerably changed over time, displacing the service core from its traditional central position in the building plan. Yeang (2006) also emphasizes that the architects are now encouraged to think ‘outside the box’ throughout the design process and develop more complex possibilities for the design of the service core. As explained by the authors, the conventional approach to service core design in the past was to have the service core in the central position mostly, but today, much more complicated configurations for the service core could be utilized.

CHAPTER 3

PLANNING CONSIDERATIONS OF TALL BUILDINGS

The design process of a tall building is a significantly complex procedure taking into account a multitude of factors and variables; and it is essential for the designer to acknowledge and implement these principles in an integrated manner to achieve an optimal building design. The role of the architect in such a complex design process is very important, and requires a thorough understanding of the complexity of the issues involved in the architectural design, which should satisfy many requirements and special considerations. In this context, in the architectural design process of a tall building, some components in the planning considerations such as planning modulation, lease span, building function, floor-to-floor height, service core planning, and structural system must be taken into consideration. Since the decision about each component influences all other aspects during the design process, investigation of these factors as well as relationships among them is crucial for designers. This chapter outlines and provides an overview of basic planning considerations in the architectural design of tall buildings which are important for architects during their early phases of the planning and design process.

3.1 Planning Modulation

Tall building design involves establishing an appropriate design methodology based on comprehensive understanding of space requirements in order to ensure the functional performance of tall buildings. In the preliminary design phase of a tall building, the organization of the floor space is a challenge for the designer due to the different functional requirements. In this respect, as an important determining factor for the organization of the space in architecture, planning modulation provides a dimensional arrangement which is necessary for the space planning in tall buildings.

The design methodology is based on the use of a consistent planning module that serves as the basis of developing optimal dimensioning for the spaces. Planning module can be described as a standardized unit of area at a given length and width which can be arranged or fitted together in a variety of way depending on the functional requirement. The modular coordination of such standardized elements provides efficient floor space while enhancing flexibility to accommodate changing occupant needs. For this reason, planning modules are considered as the basis for the design of the vast majority of tall buildings, enabling standard dimensions for their design and construction.

The arrangement of planning modules does not only depend on the functional requirement, but also other factors such as facade design, mechanical system and structural system modulation play important role, and hence, it is important to arrange the planning modules in conjunction with these factors. For instance, the coordination between planning modules and window mullions is important for facade design, especially when the exterior is of glass and the spacing of window mullions is critical in the building elevation. Structurally, the coordination of the planning module with the structural module including column bay spacing is crucial when considering the structural constraints on the space planning. Therefore, along with the functional requirements, other planning considerations and building systems should be taken into consideration to determine the optimum arrangement for planning modulation. The successful design is considered as the one in which all these grids are integrated into a harmonious whole. For instance, the following figure taken from Kohn and Katz (2002) illustrates the lease span measurements, structural bays, and planning modules on a rectangular and repetitive floor plate. Here the structural bays and the lease span measurements are coordinated with the 5' planning module (Figure 3.1).

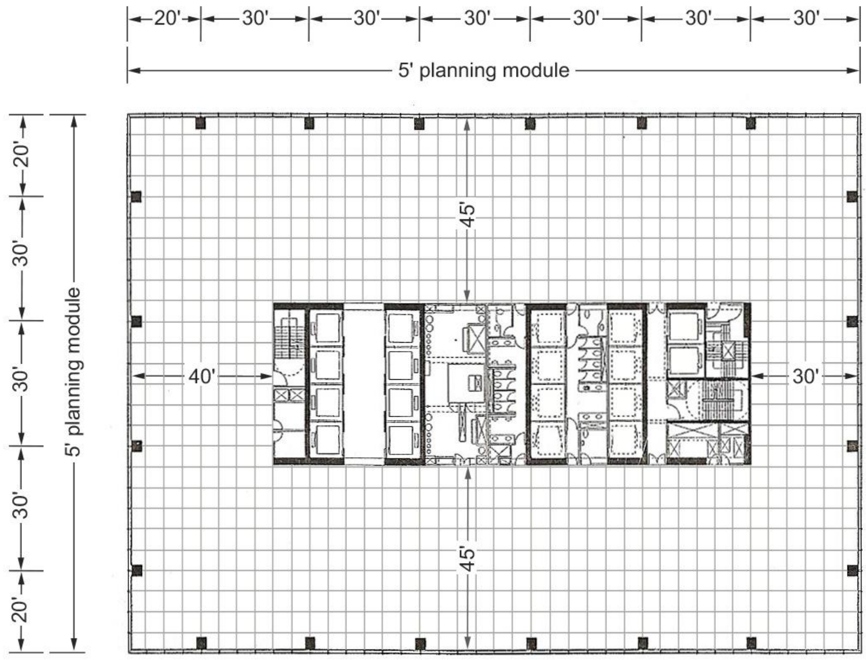


Figure 3.1 Lease span measurements, structural bays, and planning modules illustrated on a typical floor plan. (Kohn&Katz, 2002, 34).

The determination of the dimension and character of a planning module generally depends on the demand for space required, economical considerations as well as culture. In "Architecture of Tall Buildings", Ali and Armstrong (1995) define the planning module as the space one needs for living, which varies with the culture and economic class. The authors indicate that the space allowed per person for normal living functions varies significantly among nationalities and cultures in design of residential tall buildings. For instance, while in the United States, the average living area per person is 24 to 28 m^2, in Germany 108 m^2 is allowed for rented apartments (2 to 5 persons) or 21.6 to 54.0 m^2 per person.

From analysis of many buildings constructed since World War II, a planning module of 5 ft by 5 ft (1.5 by 1.5 m) is considered a normal module or a ratio of 4.5 ft to 5.5 ft (1.4 to 1.7 m) module is commonly accepted for commercial, office and residential functions. This allows for a reasonable variety of office or room widths at the building's perimeter, starting with a minimum of two module spaces of 10 ft (3 m) and ranging upward to four or five module spaces of 20 ft to 25 ft (6 to 8 m).

Additionally, the 5 feet modulation for ceiling systems in office buildings can economically be designed for lighting fixtures, diffuses, sprinklers, etc. (Ali and Armstrong, 1995)

3.2 Lease Span

Lease span, which is defined as the distance between the exterior envelopes (windows) to a fixed interior element (core wall), is an important planning consideration in a tall building development (Figure 3.2). The lease span has an important effect on interior planning, therefore when considering efficiency and flexibility, there is a need to concentrate on the lease span in tall building design. As a measure of occupiable space established by the core and exterior walls, lease span is important for the space planning in tall buildings.

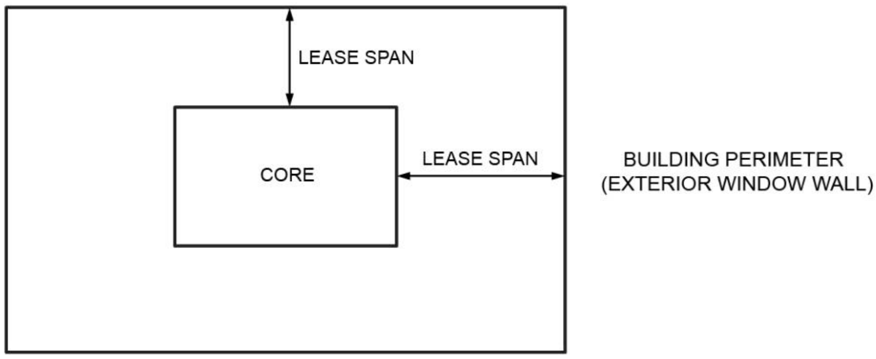


Figure 3.2 Definition of Lease Span

The primary determinant of the lease span is the function of the space as it dictates standard dimensions and characteristics for space planning. The depth of lease span varies with different functions such as office, residential, or commercial, and it is essential for the designer to fulfill the required demands for each function effectively. Particularly, when considering profitability and flexibility of office planning, it is desirable to have as few columns as possible within the lease span area, therefore, a column free floor from window wall to building core is considered as an optimum solution for office function development. On the other hand, the lease span for the hotel function is determined by typical room depths, while standard dimensions that vary depending of the user type determine the lease span for residential function.

Along with those concerning the functional requirements, there are a multitude of factors specific to each country that influences the lease span. Considering the environmental quality concerns such as the accessibility of natural light and air from outside, some countries have a requirement that all offices must have an outside exposure so as to allow ease of access for office workers and improve their performance. In such cases, even though a longer lease span allows for more flexible interior planning and initial economic benefits, a shallow lease span is preferred due to the environmental quality concerns that become the dominant factor in the determination of the lease span depth.

As a consequence, there are no international standards to determine the lease span depths due to the fact that the determination of acceptable lease spans is governed by several factors such as office layouts, hotel room standards, and environmental expectations regarding natural daylight and outside air which vary depending on the different country codes**.**

3.3 Building Function

Tall buildings are designed primarily to provide the needs of the occupancy which are determined on the basis of the functional requirements, thus, careful consideration for building type utilization must be performed during the design process. As a major dominant factor that directly affects other design factors, and hence the building organization, building function is of primary concern which requires to be assessed at the early stages of tall building design.

In the design of tall buildings, it is essential for the architects to develop design solutions that are functionally accommodating, which result in spaces that are efficient, flexible and responsive to the occupant needs. According to the functional types of tall buildings, which can be divided into single-function and multi-function development, the design solutions are developed as separate entities for their specific function. For instance, in a single-function tall building with architectural repetition of floors as in the case of office type building, the program may be fairly straightforward. However, as buildings become more complex with multiple functions as in the case of office with hotel type building, which require different planning and structural considerations, a more detailed comprehensive program is required. In order to provide an appropriate design for each function, it is necessary for the designers to understand these two building types, namely ‘single-function’ and ‘multi-function’ tall buildings.

a) Single-Function Tall Buildings

Single-function tall buildings designed for a specific function such as office, hotel or residential functions, have been among the most widely used building types for tall buildings since their early examples in the history. Historically, the tall building has been developed as a single-function building, consisting predominantly of office function; over time, however, they have incorporated different functions, including hotels and residential facilities. As a unique building type designed for a specific function, single-function building necessitates different design solutions and different set of conditions depending on its function, and the designers should be aware of these considerations during the design process.

According to the official Council of Tall Buildings and Urban Habitat (CTBUH) criteria for the defining and measuring tall buildings, a single-function tall building is defined as one where 85% or more of its total floor area is dedicated to a single function. Office, hotel and residential functions are considered as major functions in tall building development, and the major differences between these building types can be recognized in their functional requirements. In this regard, there are a multitude of requirements specific to each function; among these may be cited circulation patterns of designated users; structural factors; usable space generated; type, size and diversity of services required; and so on. For instance, office and commercial buildings require maximum flexibility in layout, namely large open rentable spaces which can be subdivided by movable partitions or conventional partitions. Residential or hotel functions also require spans for habitable space needs.

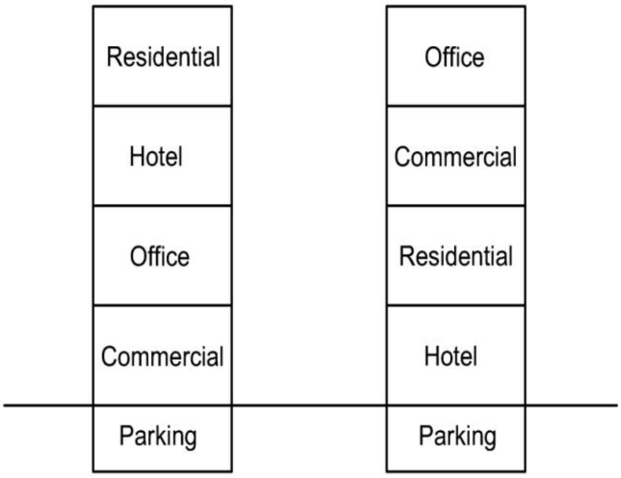
Consequently, considering different planning considerations for each function, it is essential for the designers to investigate users of each function and their needs in the planning phase.

b) Multi-Function Tall Buildings

The multi-function tall building combines more than one type of functions such as office, hotel and residential within the same building, each function having its own design requirements. Multi-function tall buildings can be classified into several types according to their complexity. The classification of Kim and Elnimeiri (2004) is as follows:

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

The multi-function tall building has much potential to provide functional advantages over the single-function building, however, in such a case, the attempt to combine several functions in a building presents the designer with several design problems. According to Kim and Elnimeiri (2004), not many such buildings have been constructed around the world, mainly due to the difficulty of the design of this building type in terms of efficient space and efficient structural system. The vertical location of functions is important for the development of an optimum design; as such, 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, 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. 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 optimum design for multi-function tall buildings (Figure 3.3).



(a) (b)

Figure 3.3 (a) Architectural design point of view; (b) Structural design point of view

According to the official Council of Tall Buildings and Urban Habitat (CTBUH) criteria for the defining and measuring tall buildings, a multi-function tall building is defined as the building that contains two or more functions, where each of the functions occupy a significant proportion of the tower's total space. This 'significant proportion', according to CTBUH, can be judged as 15% or greater of either the total floor area, the total building height, or in terms of number of floors occupied for the function. In addition, support areas such as car parks and mechanical plant space do not constitute multi-use functions.

3.4 Floor-to-Floor Height

Floor-to-floor height mainly consists of floor-to-ceiling height, the depth of the structural floor system, and the depth of the space required for accommodating the horizontal mechanical and electrical services (Figure 3.4). The overall depth of the floor is crucial for tall buildings due to the fact that a small difference in this dimension, when multiplied by the number of floors, can have a major effect on the overall height. Implicitly, this relatively small difference affects the overall economics of the building due to the expansion of all vertical elements. Additionally, this dimension has an impact on the overall building energy conservation since it affects the area of the exterior building skin exposed to the outside climate.

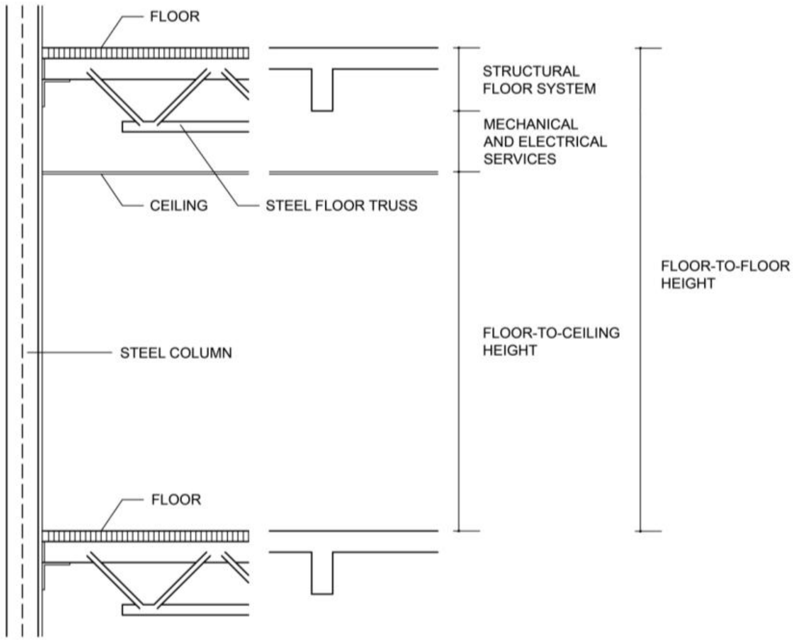


Figure 3.4 Floor-to-floor height

For tall buildings, it is important to optimize the design of building height by minimizing the floor-to-floor height, while maintaining the floor-to-ceiling to an acceptable minimum. The floor-to-ceiling height is generally determined by the building function and the relevant building regulations. In “Architecture of Tall Buildings”, Ali and Armstrong (1995) emphasize that commercial functions require a variety of ceiling heights ranging between 2.7 and 3.7 m; office functions necessitate ceiling heights of approximately 2.5 to 2.7 m, while residential and hotel functions require ceiling heights of 2.4 to 2.7 m.

The difference between floor-to-floor height and floor-to-ceiling height is the space for accommodating the structural floor system as well as horizontal mechanical and electrical services within either the ceiling void or the structural floor system. The depth of structural floor system plays an important role for floor-to-floor height, and varies significantly depending on the size of the structural bay, the magnitude of the loads, and the type of floor framing system. The horizontal mechanical and electrical services can be suspended from the structural floor system with horizontal distribution below it over the suspended ceiling. In the case of steel structural system, there is the possibility of providing space for the horizontal mechanical and electrical services within the structural floor system with the use of trusses as they permit the passage of ductwork and piping. In either case, the horizontal mechanical and electrical services must be integrated with the structural system. Another method to distribute horizontal mechanical and electrical services is to provide a raised floor system which is placed above the structural slab.

3.5 Service Core

Service core is one of the most important component of the tall building due to its major function of providing the vertical transportation for occupants and the service systems, as well as contributing to the structural stability of the building in some cases when the service core acquires the function of providing structural rigidity. (Figure 3.5).

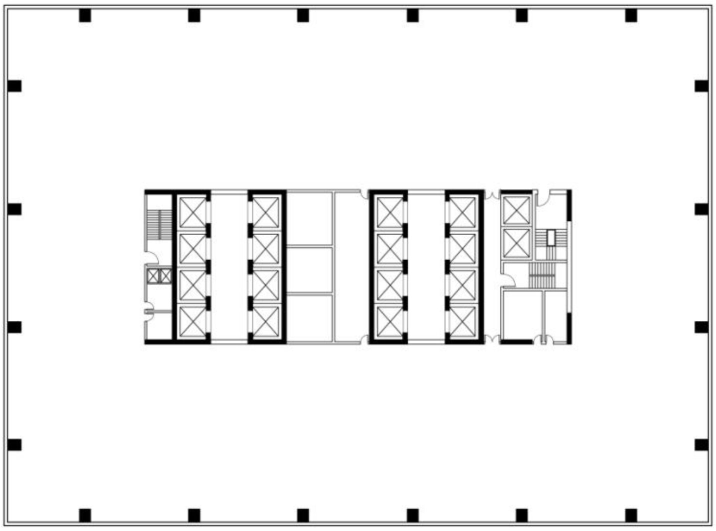


Figure 3.5 Service Core

Functionally, service core provides means of accommodating vertical circulation systems and services, such as elevators, staircases, mechanical and electrical risers. Service core becomes more important in tall buildings due to the fact that the need and necessity of vertical transportation increases as buildings expand in height. In this complex design, service core has a major function of tying the building together from an operational standpoint, providing the necessary service systems for tall buildings.

Structurally, the design of service core is crucial in the case of interior structures in which the core is designed as a structural element to provide stability. In that case, service core provides the principle structural element for both the gravity load-resisting system and lateral load-resisting system, with the later becoming increasingly important as the height of the building increases.

From the sustainability point of view, service core represents a growing and increasingly important part of the tall building, and thus, designers focus on service core design for tall buildings, recognizing its importance as a tool to improve the sustainability. Ali and Armstrong (2008) emphasize the importance of service core in terms of sustainability as "The service core is a distinctive feature of a tall building and its design plays an important role in the success and sustainability of the whole structure". The authors further state that the more time spent on the core design, the more efficient and sustainable the building can be.

Economically, as building height increases, construction cost of service core gains importance, covering a large percentage of the total building cost due to its large scale. Since the size of the service core is a basic factor in determining the building cost, it should be the smallest possible size while still effectively accommodating the necessary functions. For this reason, it is essential for designers to develop design strategies based not only on creating an efficient internal layout for service core, but also on minimising its size to an acceptable level in order to achieve an economic layout for the building.

In his recent research, Trabucco (2010) points out the importance of service core as "Even though the service core of a tall building is disregarded by many as a consequence of its technical nature and its hidden positioning, it is a key factor for the successful design of a skyscraper". As it is indicated by Trabbuco (2010), in spite of its technical nature and hidden positioning, service core is one of the foremost design considerations for the level of design efficiency achieved throughout the building, as it includes all functional requirements related to vertical transportation and service systems, and thus reflects the operational performance of the building. Hence, the architects must be aware of the fact that the design of service core is of special concern which requires to be assessed at the early stages of tall building design.

Consequently, many aspects described above established the importance of service core as an important design consideration. However, the service core in tall buildings is a complex field touched upon here, but explored further in the view of a more comprehensive approach in the subsequent sections, under the topic of "Service Core: Configuration and Typologies".

3.6 Structural System

The structural design of a tall building requires primarily consideration of the lateral loads resulting from wind and earthquake due to the increasing importance of these loads as the building height increases. Considering this fact, structural design of tall buildings requires an understanding of the structural behavior of such buildings under lateral loading which is fundamentally different from other building types, and thus requiring special structural systems to satisfy the sufficient resistance.

The structural systems for tall buildings have evolved toward more efficient systems since the rigid frame system which is the predominant structural system for the early tall buildings. Since then, many new structural systems which are efficient and economical for different ranges of heights have been developed, ranging from the rigid frame, outrigger to tube systems in order to satisfy structural requirements. The evolution of structural systems, based on new structural concepts and newly improved materials as well as construction techniques, has allowed tall buildings to reach greater heights by providing sufficient stiffness and resistance to lateral loads.

Currently, there are many researches and studies in order to classify the structural systems of tall buildings. According to a recent classification by Ali and Moon (2007), the structural systems of tall buildings can be divided into interior and exterior structures, based on the distribution of the components of the primary lateral load-resisting system over the building.

3.6.1 Interior Structures

The system is categorized as an interior structure when the major part of the lateral load resisting system is located within the interior of the building. However, any interior structure is likely to have some minor components of the lateral load-resisting system at the building perimeter. Interior structures are generally characterized by the presence of a service core which bears at the same time a structural function. On these structures, the core is usually placed in the centre of the building so as to withstand lateral forces and avoid torsional movements. Consequently, the layout of the core is critical for interior structures since it plays a significant role in the way the structure resists the lateral loads. Different types of structural system for the category of interior structures are presented as below:

- **Rigid frame systems**

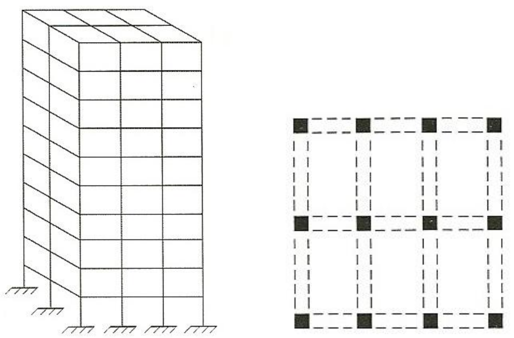


Figure 3.6 Rigid Frame System (Source: Günel and Ilgın, 2010)

- **Flat plate/slab systems**

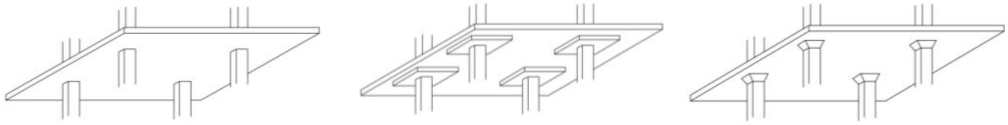


Figure 3.7 Flat Plate/Slab System (Source: Günel and Ilgın, 2010)

- **Core systems**

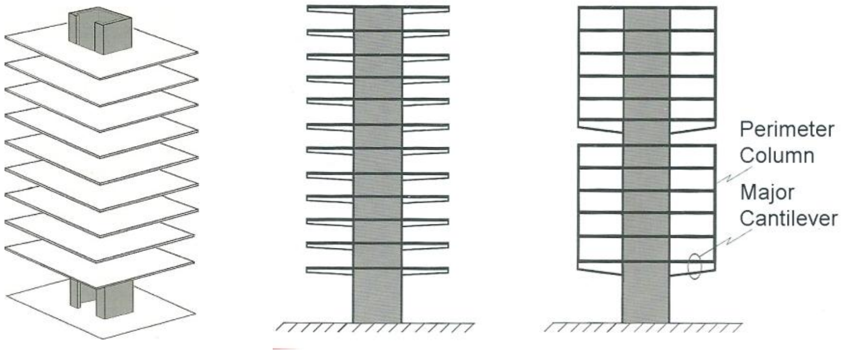


Figure 3.8 Core System (Source: Günel and Ilgın, 2010)

- **Shear wall systems**

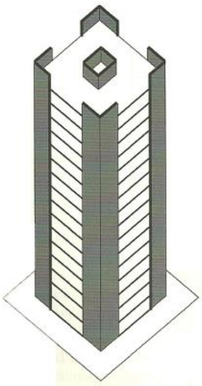


Figure 3.9 Shear Wall System (Source: Günel and Ilgın, 2010)

- **Shear walled frame and Braced frame systems**

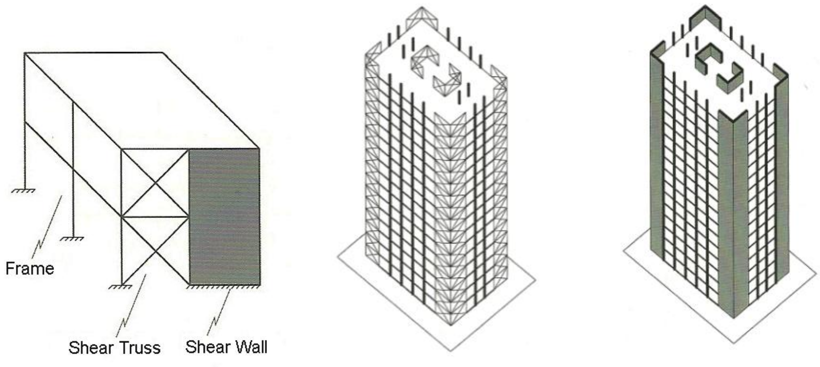


Figure 3.10 Shear walled frame and Braced frame systems
(Source: Günel and Ilgın,2010)

- **Mega column (Mega frame, Space truss) and Mega core systems**

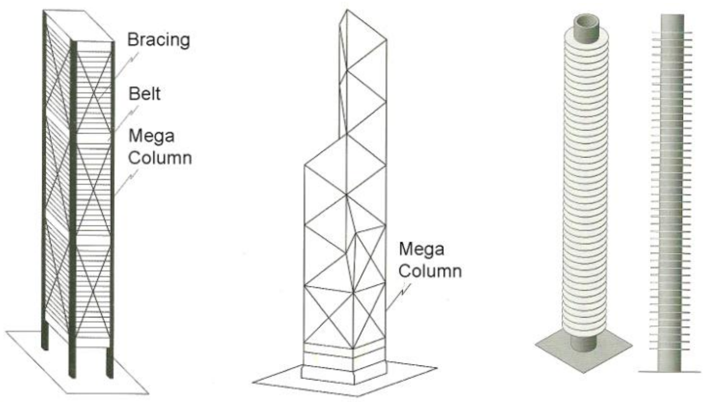


Figure 3.11 Mega Colum and Mega Core Systems
(Source: Günel and Ilgın, 2010)

- **Outriggered frame systems**

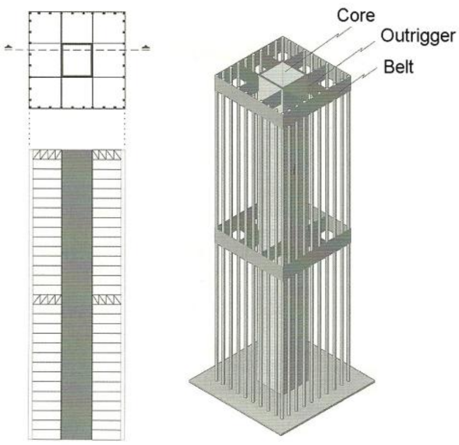


Figure 3.12 Outriggered Frame System (Source: Günel and Ilgın, 2010)

3.6.2 Exterior Structures

The system is categorized as an exterior structure if the major part of the lateral load-resisting system is located at the building perimeter. On exterior structures the lateral load-bearing system is contained in the structural elements on the buildings perimeter as in the case of tube structures, as opposed to the interior structures where such elements are within the building's perimeter. In other words, exterior structures tend to concentrate as much lateral load-resisting system components as possible on the perimeter of the building to increase its resistance to lateral loads. In such cases, the service core is free from any structural function and its design becomes more flexible. The structural system for the category of exterior structure is tube systems; namely, framed-tube systems, trussed-tube systems and bundled-tube systems.

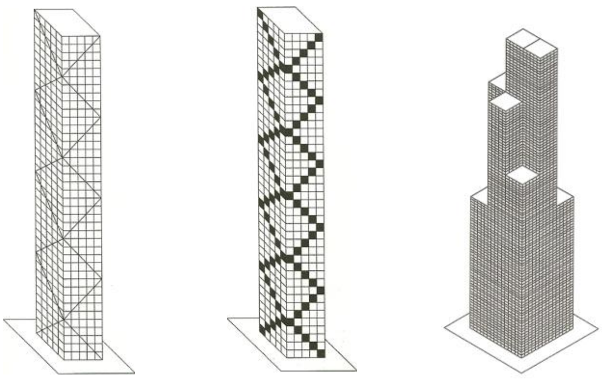


Figure 3.13 Tube Systems (Source: Günel and Ilgın, 2010)

CHAPTER 4

SERVICE CORE CONFIGURATION AND TYPOLOGIES

The development of the tall building is accompanied by an increasing awareness of the importance of service core as a planning consideration that requires integration from the early stages of the design process. This chapter investigates the service cores with regard to their configuration in tall building planning, together with a discussion of these in terms of different aspects of the design process including functional, safety and security, structural as well as environmental concerns. In exploring the general considerations fundamentally important to the service core planning process, first the definition of the term ‘service core’ is presented. Following this, the major functions and elements with special emphasis on the vertical transportation system that is critical for the design of tall buildings are presented. Finally, the chapter provides the author’s classification for the service core configuration as part of the concern of this thesis and describes the general design characteristics of each configuration.

4.1 Definition of the Service Core

The definition of the service core necessitates a comprehensive approach that takes into consideration various design disciplines such as architectural, structural and mechanical. This mostly owes to the fact that in common usage, the term ‘service core’ covers a wide range of interrelated architectural and engineering aspects. In this regard, there are different approaches and theories to the definition of service core. The following paragraphs present the approaches of several authors regarding the definition of service core.

Architecturally, the term ‘service core’ emphasizes the role of the services included in it; that is, the part where the major components of services, vertical transportation and utilities are concentrated to function as the vertical service system in a building. In this respect, service core has a servant role as regards the main purposes of the building, providing space to accommodate the necessary functions related to services and vertical transportation. On the other hand, in some cases it also acquires the important function of resisting lateral loads acting as a primary member of the structural system in addition to connecting the floors with vertical service systems and, in this case, is often referred just as ‘core’ to emphasize the importance of its structural solidity. This approach, which conceives service core as an important aspect of structural performance in building design, implies mutual participation of the architect and the engineer in the early stages of the design process.

Regarding the individual elements of the service core, Yeang (2000) simply defines service core as that part of the building that consists of the lift shafts with lift cars and supporting mechanism, lift lobbies, staircases, vertical M&E riser ducts toilets and air handling units in some cases. Additionally, the author remarks that these elements are almost always placed together forming a vertical core like structure ideally connecting the floors vertically due to ease of maintenance, accessibility and economic factors.

Another approach to service core definition is proposed by Trabucco (2010) in his recent research ‘Historical Evolution of the Service Core’, which can be viewed as an introduction of a more comprehensive analysis on service core design in tall buildings. In this research, Trabucco (2010) proposes an approach to understand and formalize the ‘service core’, stating “An element that gathers the space necessary to provide visual, physical and functional vertical connections that work effectively to distribute services through the building”. As is obvious from the definition proposed by the author, service core acquires the important function of gathering the necessary space for vertical connection in tall buildings, incorporating a wide range of interrelated architectural and engineering aspects.

From an ecological point of view, Chakraborty (2010) describes the service core as that inseparable volume of the building which houses the vertical linkages and could be used as a passive design tool to buffer the habitable/usable volume from harsh sun or cold winds through thoughtful planning and design incorporated right at the concept development stage. This approach to the definition of the service core reveals the importance of service core design in optimizing energy consumption of the building.

As is obvious from the definitions provided above, there are several approaches to the definition of service core due to the variety of considerations involved in its design process. As such, the definition of service core is controlled by a number of criteria; some are related to its functional requirements and major elements, and others related to structural stability and safety as well as environmental considerations such as daylight and natural ventilation. The definition proposed by Trabucco (2010) can be used as the basis for the proposed research since it presents the complexity of the service core as a particular building component and clearly states that the design process itself creates different set of conditions than other building types, incorporating a highly organized system of vertical connection in tall buildings.

4.2 Function and Elements of Service Core

The design process of the service core is essentially different and more complicated for tall buildings in comparison with the other building types due to the large number of individual elements involved, and thus requires a high level of coordination and collaborative study among different disciplines. The design of the service core is primarily governed by considerations that include the fundamental requirements of;

- meeting the necessary standards for fire protection and emergency escape for the safety of the occupants,
- achieving an effective vertical transportation,
- providing means of accommodating mechanical and electrical services,

- creating an efficient internal circulation pattern,
- and, in some cases satisfy the requirements of structural resistance.

The major role of all these components is to provide accessibility and functionality to the spaces devoted to occupancy in the building taking into consideration the occupancy scenario such as single, double or multiple tenants. Hence, it is essential for designers to understand each of these different parts and their relationships so as to achieve an efficient design. Kohn and Katz (2002) indicate that the buildings planned for single users have different priorities, typically requiring a greater level of service in elevators than those for multiple tenants, and that is often reflected in the arrangement of the core elements.

In tall buildings, the combination of the services necessary for the use of the building usually requires a complex service core and user circulation; therefore, these elements tend to be concentrated on the floor rather than dispersed. That is stated by Yeang (2000) in his book 'Service Cores' as, "Efficient building design typically integrates utilities and services into a compact core or multiple cores, such as elevators, stairs, mechanical rooms and shafts, and interior columns". In this respect, concentrating all the service systems within the same space is generally recognized as efficient in terms of functional performance and ease of maintenance. This also suggests that the service core must be arranged with the greatest level of compactness and efficiency possible, resulting in a geometrically regular form containing all of the typical service core functions inside.

The challenge in understanding the numerous elements of the service core is the major issue in attempt to understand its design process. In his research "An analysis of the relationship between service cores and the embodied/running energy of tall buildings", Trabucco (2008) classifies the servant functions necessary for the existence of the service core as; a) services; b) subservices; and c) core. The author perceives services as the main servant facilities of the building necessary to its existence and operation. Subservices are those elements whose subservant role derives from being necessary to the operation of the main services, and the core is the structural shell that often encircles the services, as explained below.

a) **Services:** the main servant facilities of the building necessary to its existence and operation, such as elevators, their shafts and corridors, egress stairs and secure spaces, machine and electrical/communication rooms, toilets and storage rooms.

b) **Subservices:** vertical risers, ducts, pipes and chutes, whose subservant role derives from being necessary to the operation of the main services. They are generally placed in the residual areas left free by the design of the main utilities.

c) **Core:** the structural shell that often encircles the services. The core exists when the structural scheme of the building requires shear walls/trusses or moment-resisting frames to withstand the horizontal forces; otherwise, it is omitted.

The coordination of the overall layout of the elements comprising the service core, especially the elevator conception in connection with the service core layout, requires careful consideration in tall buildings. This is mainly because the need and necessity of vertical transportation system increases with height which, in turn, causes the size of the service core to become excessively large. In general, this is explained by the fact that the number of elevators increases disproportionately to the increased area obtained by increasing the height of the building. Hence, vertical transportation is an important factor which has considerable influence on the planning of the service core as a result of requirements for the number and size of elevators as well as escape stairwells and smoke extraction. User comfort in terms of rapid response times for elevators also plays an important role in determining the number of elevators and hence the dimension of the core. These issues result in compromises, which impact the profitability of the building. Consequently, in order to keep the service core within a reasonable size while maintaining an acceptable comfort level of the elevators in tall buildings, the vertical transportation system is usually based on elevator zoning system in which the building is divided into a number of elevator zones such as low, mid and high zones (Figure 4.1).

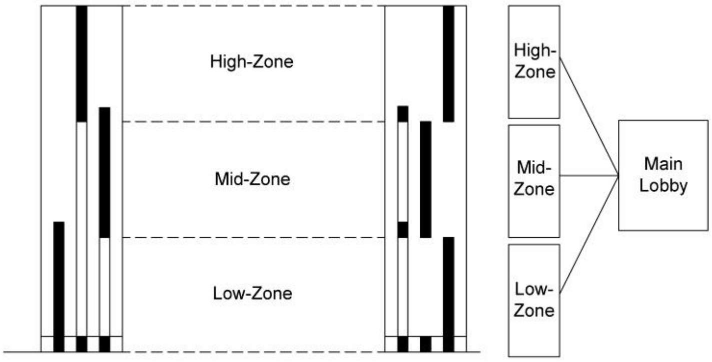


Figure 4.1 Zoning System (Choi, 2004)

The elevator zoning system, namely the grouping of required elevators with elevator banks, provides the vertical transportation in the design of tall buildings based on building space footage so as to reduce the footprint and achieve space efficiency. In order to achieve this, the elevators are designed so that some of them serve the lower floors, some of them serve the mid-level floors, and others serve the upper floors. However, as building height increases, it becomes necessary to improve the capacity of elevators and use transfer floors between the elevator groups such as sky lobbies. Hence, the design of vertical transportation systems for such buildings generally involves the implementation of the two recently developed system; namely, sky lobby system and double deck elevator system.

As building height increases, the elevator zoning system requires transferring between elevator groups to reach the ultimate destination floor. In this regard, sky lobby system provides occupants with a convenient transition from vertical to horizontal movement. Thereby, each zone with an independent sky lobby can be planned to be served from the ground floor level directly by express elevators with a transfer to local elevator systems. The concept of changing to another group of elevators on some of the upper floor creates two or more buildings vertically connected, each having its own local elevator system so that lobby serves as the starting point of a different function in multi-function buildings (Figure 4.2).

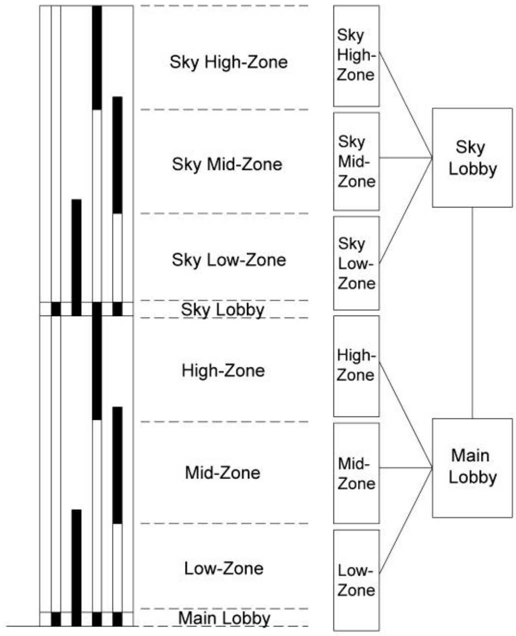


Figure 4.2 Sky Lobby System (Choi, 2004)

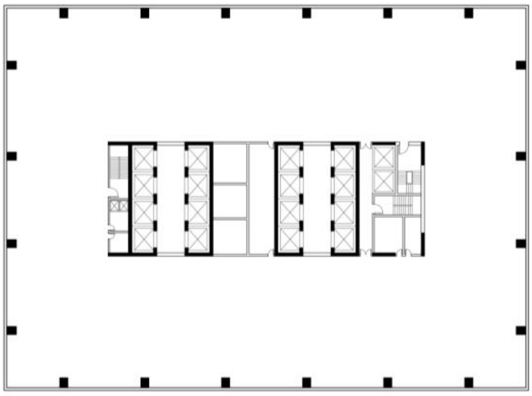
Double deck elevator system comprises two elevator cars stacked vertically in a common elevator frame so that passengers at two consecutive floors are served simultaneously. The major principle of double deck elevator system is to reduce the large amount of space occupied by elevator shafts by increasing the demand of elevator capacity. The double-deck elevator group requires less core space in a building compared to a conventional single deck elevator group. This aspect is important especially in tall buildings where the floor area required by the elevators is great.

As a consequence, the general layout of service systems is different and more complicated for tall buildings mainly due to the increasing requirements of vertical transportation of occupants and services. The elevator is one of the most significant components due to its responsibility for the greatest amount of area of the service core. Furthermore, the design of the elevators, besides responding to concerns regarding serviceability and performance, should also take account of occupant comfort in terms of rapid response times, elevator size, areas to be served, all of which develop in relation to the profitability of the building. Recent developments such as sky lobby system and double deck elevator system allow designers to satisfy the requirements of vertical transportation system using less amount of space thereby reducing costs and increasing overall efficiency and performance.

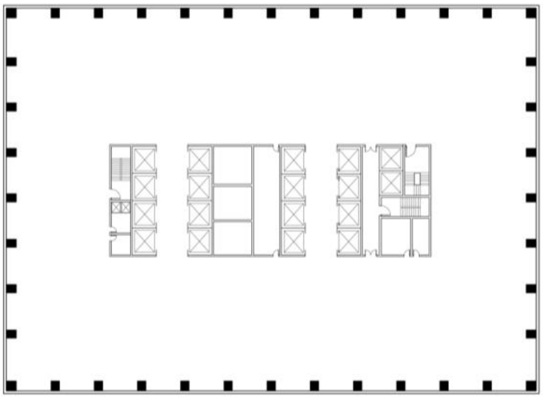
4.3 Classification of Service Core Configuration

In the design of tall buildings, there is a wide variety of alternative configurations for the service core to meet the diverse possibility of the building objectives. The determination of service core configuration is probably the most challenging aspect of a tall building project, due to the existence of different possibilities of its location, shape, number and arrangement. However, even though each building is unique and necessitates different implementation of service core, the solution that is most appropriate for a particular case depends on the assessment of the common contextual factors. Furthermore, there is an increasing emphasis for a holistic approach to service core design taking into consideration all aspects of design including functional, safety and security, structural as well as environmental to enhance building performance. In order to conceptualize an adequate configuration for the service core, it is essential for the designers to be aware of all these factors.

From the structural design point of view, service core configuration is considered as an important aspect of structural performance in tall building design especially when the service core satisfies structural requirements. In such cases, the determination of the service core configuration is dictated by the structural requirements in which the rigidity and stability are often the dominant factors in design. Referring to the classification of Ali and Moon (2007), this approach is attributed to the interior structures, where the service core is considered part of the load-bearing system. This approach possesses geometrically regular form and symmetric distributions of resistant elements, and hence, the service core is generally placed in the centre of the building so as to withstand lateral forces and avoid torsional movements. In this case, the structural system does not rely entirely on building perimeter structures but also on the service core in resisting lateral forces, thereby allowing the exterior columns to be more widely spaced (Figure 4.3a). On the other hand, exterior structures rely entirely on building perimeter structures in resisting lateral forces; and the service core is not considered as part of the load-bearing system. This enables the service core to be omitted; thereby greater design variance becomes possible (Figure 4.3b).



(a)



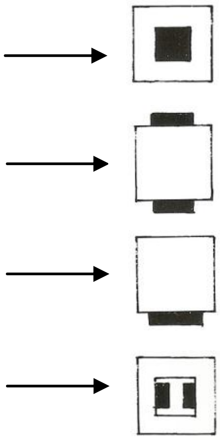
(b)

Figure 4.3 (a) structural service core; (b) non-structural service core (schematic drawing)

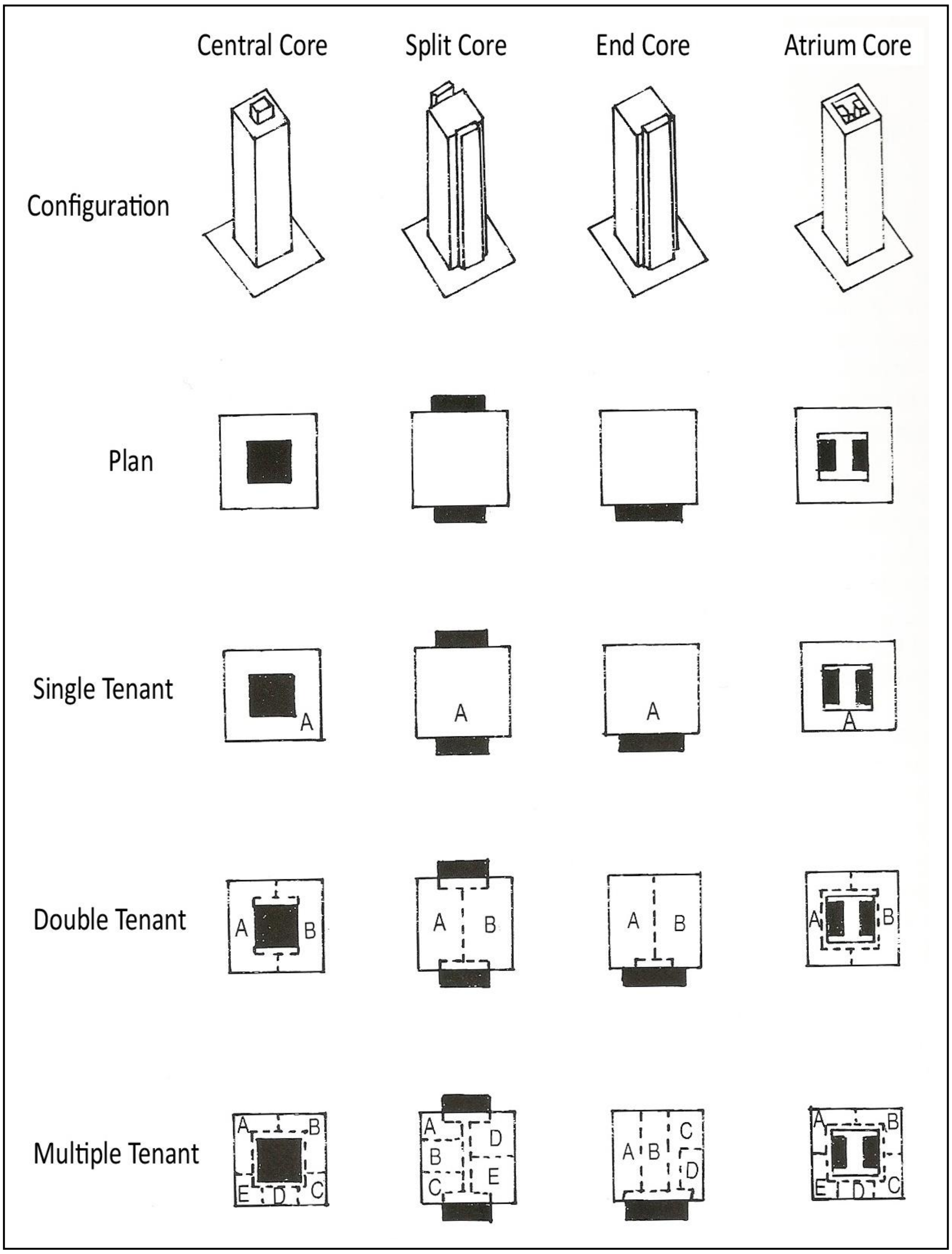
The increasing emphasis on the sustainability and the development of ways of incorporating it in the design of tall buildings, results in concepts of service core configuration that satisfy the requirements of sustainability as well. Considering the increased interest in sustainable design, recent efforts are directed by designers towards alternative configurations of the service core since it is recognized as being one of the major aspects of tall buildings that could significantly contribute in optimizing energy consumption. As an important passive design tool recognized by designers for tall building design, service cores have several benefits such as natural ventilation, shading, and natural lighting, thereby making an important contribution towards lowering the energy consumption of a tall building. This approach, which conceives of service core configuration as an important aspect of energy performance in tall building design, necessitates adopting a suitable design strategy for the service core so as to achieve an optimized tall building design with regional climate adaptability, providing significant energy reductions related to regions. Thus, it is essential for the designers to be aware of the importance of design decisions regarding the service core configuration at the initial stages of the design process not only for structural reasons but also for obtaining a less energy intensive building model.

There are currently different investigations concerning service core on account of its diverse planimetric configuration. In his book entitled “Service Cores”, Yeang (2000) discusses basic design strategies for service cores, where he classifies the common service core configurations as;

(a) central core
(b) split core
(c) end core
(d) atrium core

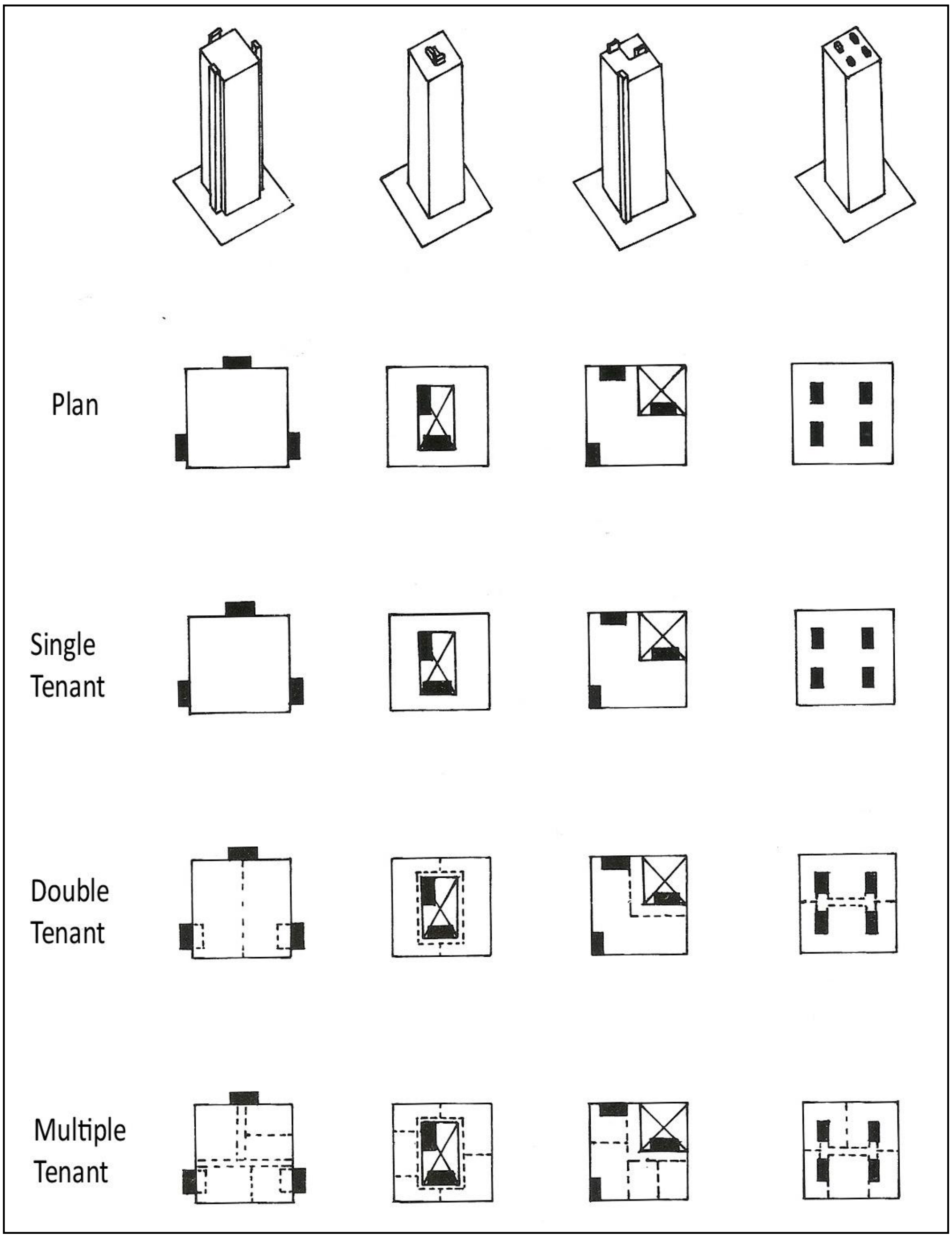


According to the author, the configuration of the service core stems from these four generic types, which are used in designing the floor plates that meet the building`s objectives. Additionally, the floor-plate configuration in relation to the service core position must allow for different tenancy options (e.g. single-tenant, double-tenant, multiple-tenant), each option having different partitioning, fire-escape, protected fire-lobby and space efficiency implications (Figure 4.4).



(a)

Figure 4.4 Possible shapes, numbers and locations of service cores
(a) Generic arrangements (Yeang, 2000)



(b)

Figure 4.4 Possible shapes, numbers and locations of service cores
(b) Hybrid possibilities (Yeang, 2000)

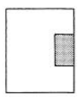
According to Kohn and Katz (2002), service cores can be classified as;

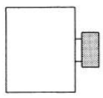
(a) center-core
(b) side core
(c) multi core

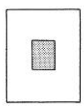
The authors consider the center-core as the most typical configuration for tall buildings, where the core integrating with the outer structure resist lateral loads more effectively and open up the perimeter for light and view; the side core configuration, where the core provides the advantage of homogeneous workplaces usually organized into one space; and the multi core configuration that is commonly used in low rise buildings, those with very large or narrow floor plates.

Referring to the studies of Yeang (1991, 2006), Trabucco (2008) takes these ideas further, emphasizing that the unconventional design of service core, where the service core is placed on the exterior or perimeter of the building, makes an important contribution towards reducing the energy consumption of a tall building. Along with the service core configurations inside the building such as the central core configuration, the author reveals the benefits of the perimeter and external service core, both of which provide direct connection to the outside of the building mainly due to energy consumption criteria.

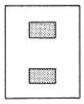
In “Mechanical and Electrical Equipment for Buildings”, Grondzik et.al. (2010) emphasizes that the service core can be related to the remaining service floor area in any of several ways. According to the authors, service cores can be classified as;

(a) edge core →


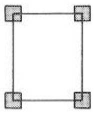
(b) detached core →


(c) central core →


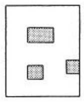
(d) two cores



(e) corner cores



(f) random cores



The authors emphasize that the central core is the most familiar arrangement while frequent variations include a core at the edge or one that is detached, two cores symmetrically placed, corner cores, or core services dispersed somewhat randomly (Figure 4.5). The edge and the detached cores give great flexibility to the rental floor area, with light and view for core spaces. The central core expands readily at the roof and the ground floor, and has clear circulation and fairly flexible rental space. Two-core is a popular, workable arrangement. The corner cores give great flexibility to rental floors but are difficult at the roof and ground floor. Random cores generally occur in low-rise buildings, in which the benefits of repetitious plans are minimal (Figure 4.6).

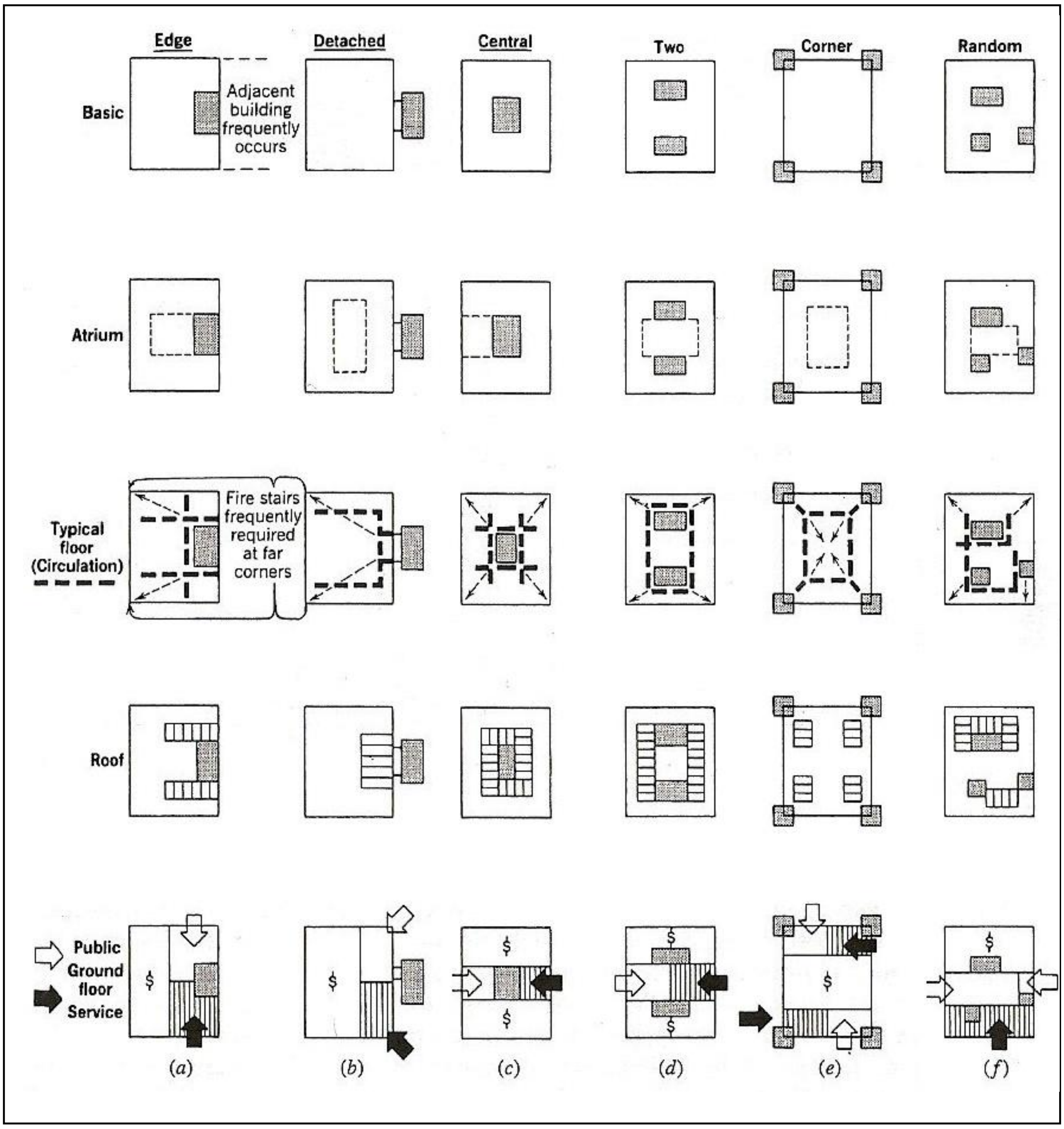


Figure 4.5 Comparison of core arrangements and building plans (a) The edge core; (b) The detached core; (c) The central core; (d) Two-core; (e) The corner cores; (d) Random Cores (Grondzik,et.al. 2010)

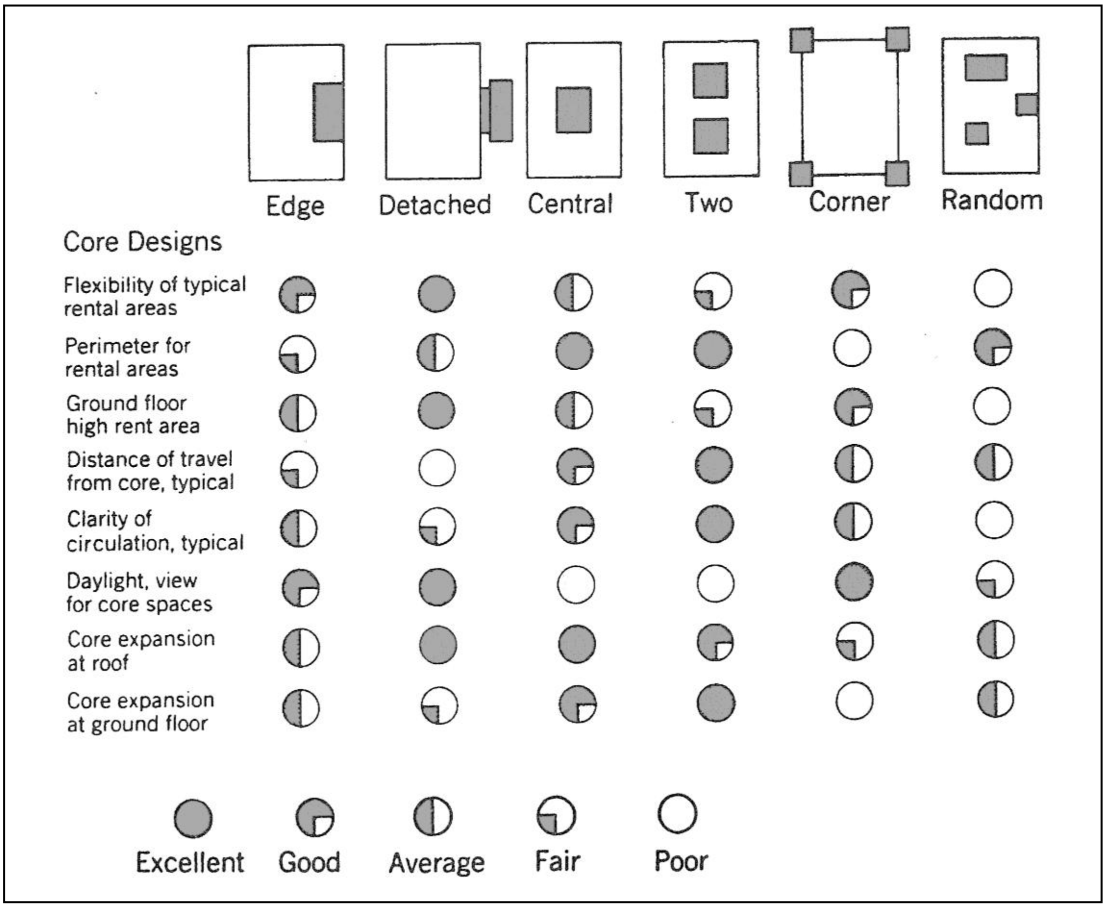


Figure 4.6 Building Characteristics and Core Placement (Grondzik et.al., 2010)

In this research, taking into consideration the studies in the literature (Yeang, 1996, 2000; Kohn and Katz, 2002; Trabucco, 2008, 2010; Grondzik et al., 2010) the following classification is proposed by the author based on the configuration of the service core in the building's floor plate:

1- Central Core
2- Peripheral Core
3- Peripheral Split Core
4- External Core
5- External Split Core
6- Atrium Core

Table 4.1. The proposed classification for the service cores

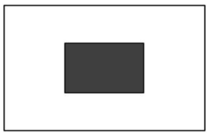
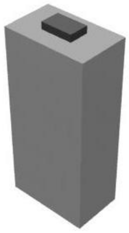
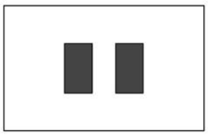
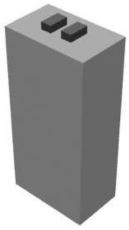
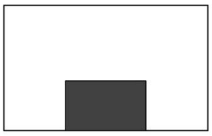
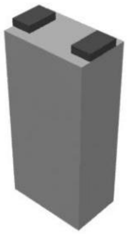
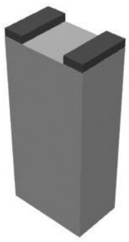
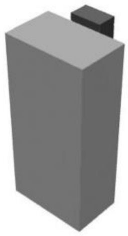
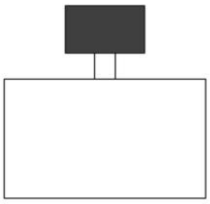
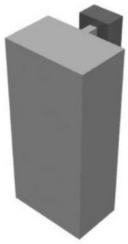
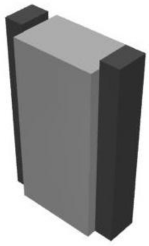
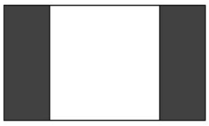
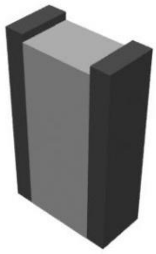
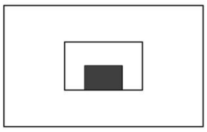
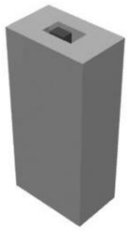
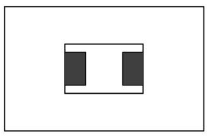
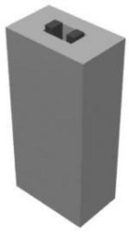
	PLAN	CONFIGURATION
CENTRAL CORE		
		
PERIPHERAL CORE		
		
PERIPHERAL SPLIT CORE		
		

Table 4.1. (continued)

	PLAN	CONFIGURATION
EXTERNAL CORE		
		
EXTERNAL SPLIT CORE		
		
ATRIUM CORE		
		

4.3.1 General Characteristics of Central Cores:

The central core configuration in which the core is placed in the centre of the building is the most widely used configuration for tall buildings (Figure 4.7). The structural relevance of the service core is generally considered as the primary determinant for this configuration, particularly for the interior structures in which the service core is part of the structure, contributing to the lateral load resistance, and in this case its dimension is dictated by structural requirements. For these structures, such a necessity requires the structural elements resisting lateral loads to be located in the centre of the building so as to withstand lateral forces and avoid torsional movements. This results in building configuration that is characterized by the presence of a central core which serves at the same time a structural function. The exterior structures, on the other hand, dictate the structural elements resisting lateral loads to be located at the perimeter of the building so that the service core does not associated with the structural system, thereby providing flexibility in meeting the requirements of different types of organizations.

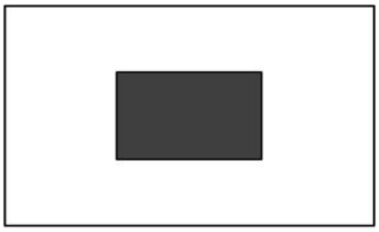


Figure 4.7 Central Core Configuration

Along with considerations for the implementation of central core configuration deriving from the structural requirements are those that are related to such of their physical attributes as overall size, planimetric configuration as well as flexibility of space divisions. As such, the centralization of vertical service spaces and mechanical systems allows an optimal exploitation of the building`s perimeter area with the lease depth that is relatively equal around the core of the building. This provides an efficient use of core-zone spaces, together with the provision of circulation to service spaces and tenant spaces by way of a perimeter corridor that encircles the core, which helps subdivide spaces easily with a minimum of circulation. Furthermore, vertical service spaces located in the center of the building provides advantages in terms of functional performance, allowing for ease of construction and easy distribution of mechanical services to the building. In addition, considering the building regulations that stipulate the maximum travel distance from the farthest point on a floor to a protected stair, central core configuration provides advantages pushing all major spaces to the perimeter and allowing easy access for fire rescue. In this regard, central core configuration can be considered as the consequence of safety concerns as well.

There are other factors taken into account in implementing central core configuration such as interior environmental quality and occupant comfort. Central core configuration is considered as one of the most appropriate solution in terms of assessment of the environmental factors in occupied spaces; such as natural light and ventilation. The need for openness in the exterior facade desired by designers for light and views, together with the introduction of the glazed curtain wall, results in the service core elements to be located in the center rather than at the perimeter. Thereby, the central configuration of the service core provides a large amount of perimeter surface, permitting natural lighting and ventilation in the building.

From a functional standpoint, central core configuration not only provides compactness but also presents several advantages such as minimization of walking distance between rooms and reduction of corridor length. However, it is important to note that the central core configuration may not be the most appropriate for buildings with smaller typical floor plates, buildings with certain site conditions, or buildings with special functions such as trading floors that are not suited to central core configuration. In the case of smaller buildings, built on small parcels, the service core is generally placed on one side of the building; as its central location creates occupied spaces too narrow to be efficiently exploited.

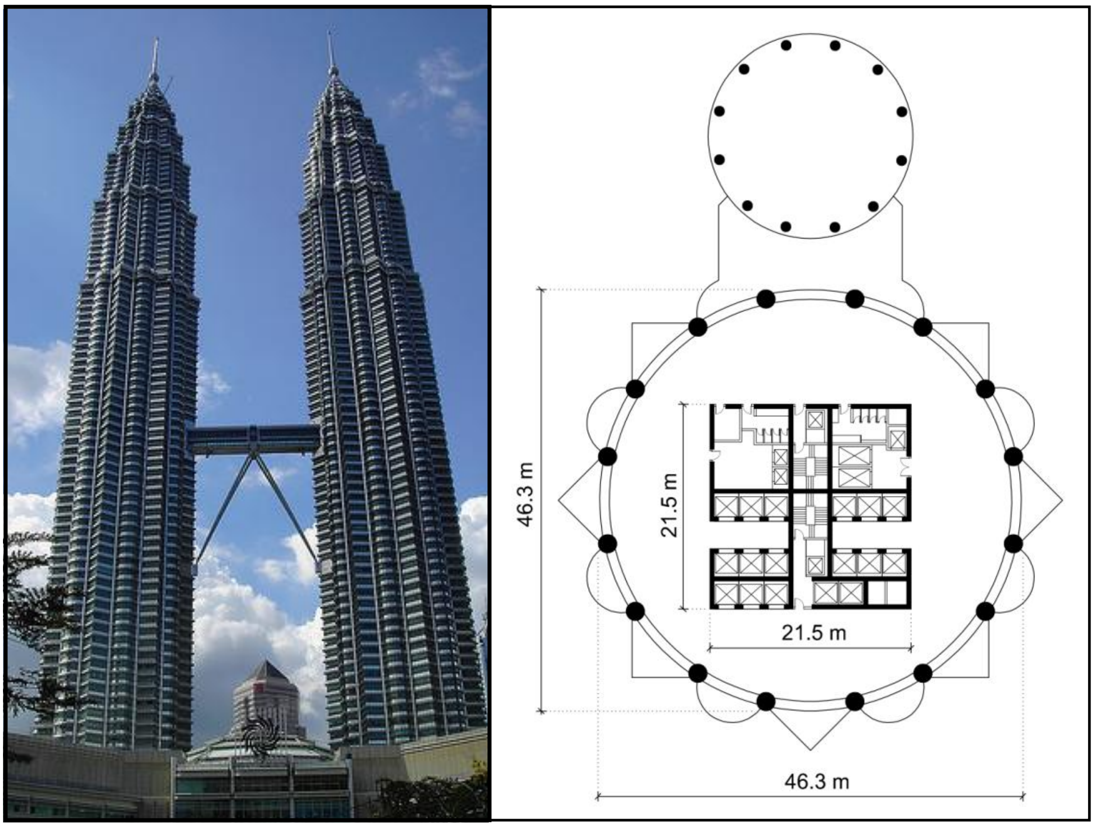


Figure 4.8 The Petronas Twin Towers, Kuala Lumpur, Malaysia, 1998
(Drawing by Zeynep Keskin, image source: www.greatbuildings.com)

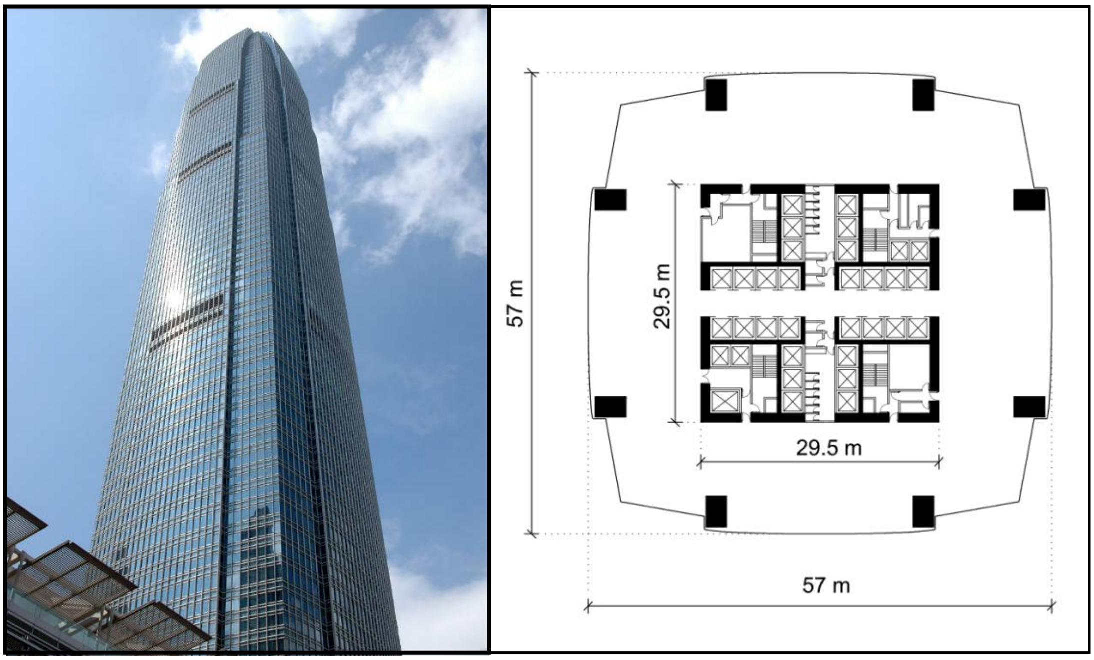


Figure 4.9 Two International Finance Centre, Hong Kong, China, 2003
(Drawing by Zeynep Keskin, image source: www.arup.com)

The central core configuration can be divided with a central space that allows for a variation in tenant sizes and accommodations depending upon individual circumstances (Figure 4.10). Generally, this approach eliminates the need for the peripheral access corridors by combining them into one wider central corridor and all components of the service core are accessed from this central space. This provides an efficient use of core-zone spaces on the floor plan as it allows larger and more flexible open perimeter spaces for occupants. Furthermore, the buildings that feature such a configuration demonstrate high efficiency in terms of space use, which is achieved by splitting the service core into two or more elements and opening up the central space for tenancy use. These elements may display variation in both number and in size according to the number of occupants and/or the number of rooms.

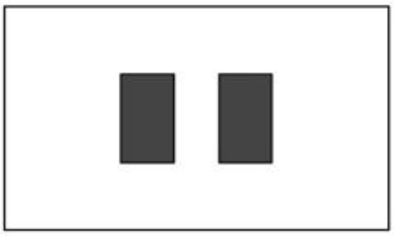


Figure 4.10 Central Split Core Configuration

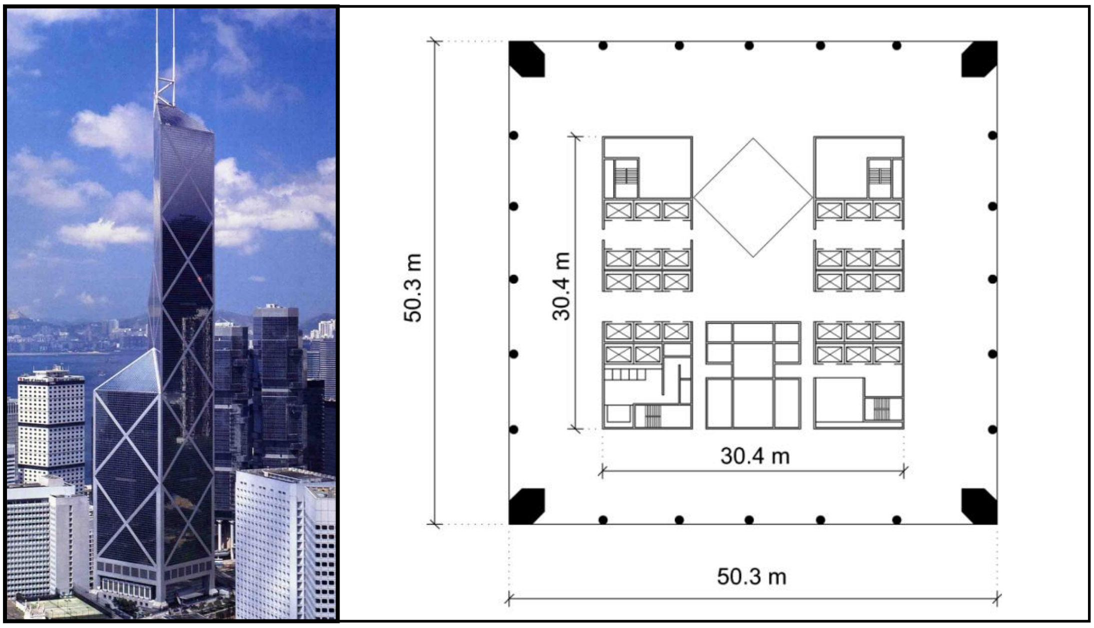
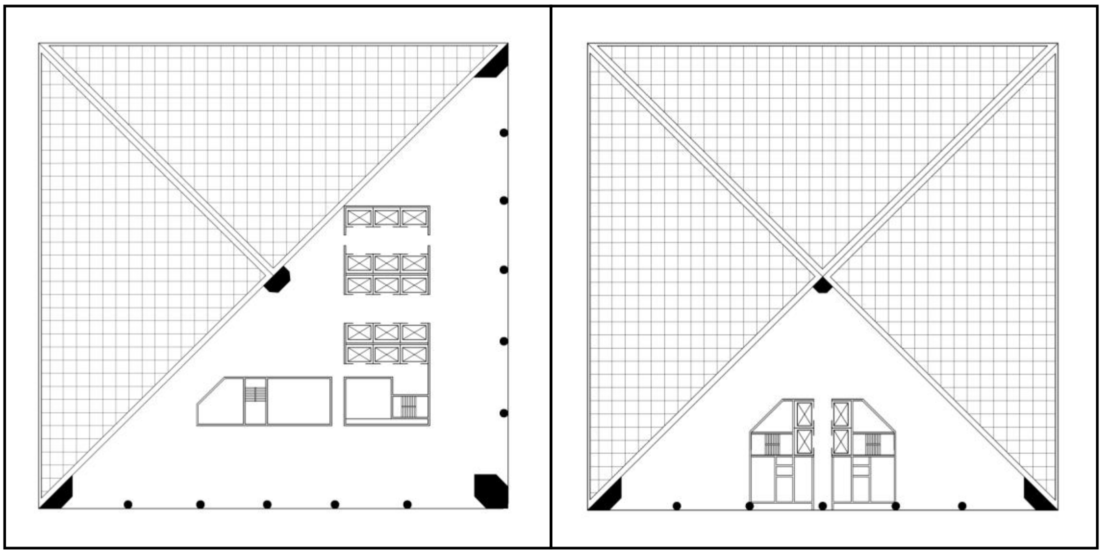


Figure 4.11 Bank of China, Hong Kong, China, 1989 (Drawing by Zeynep Keskin, image source: Bank of China, Architectural Record, January 1991)

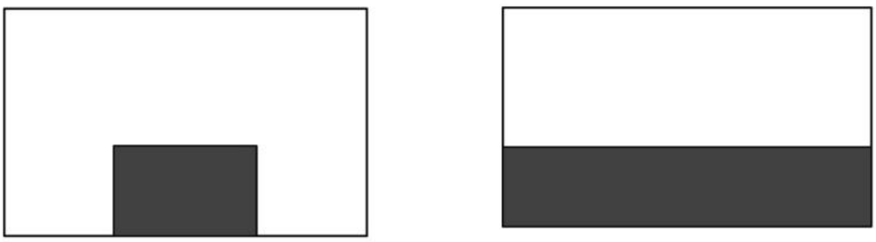


(a) (b)

Figure 4.12 Bank of China, Hong Kong, China, 1989. (a) 38th Floor Plan; (b) 51st-52nd Floor Plans (Drawing by Zeynep Keskin)

4.3.2 General Characteristics of Peripheral Cores:

The peripheral core configuration in which the core is placed on the periphery of the building is generally implemented by designers taking into consideration the size of the floor plate, site conditions as well as environmental performance criteria such as energy, daylight or natural ventilation. Conceptually, there are a variety of options for the peripheral core configuration depending on the individual circumstances, which may occupy either the entire periphery of the building or just one part of it, as illustrated in Figure 4.13.



(a) (b)

Figure 4.13 Peripheral Core Configuration

The major determinants of this configuration are the size of the floor plate and the site conditions. The peripheral core configuration is considerably more desirable for the buildings with smaller floor plates where the central configuration of service core is considered to be challenging due to the insufficiency of floor space for tenancy options or those where poor views or party walls present a problem. In such cases, the service core is usually attached to a perimeter wall, occupying the less profitable areas of the building.

The assessment of environmental performance is also important in the determination of peripheral configuration for the service core, with particular attention given to the relationship between the regional characters and the orientation of the service core. For instance, the service core placed on the hotter side of the building acts as a solar/thermal buffer while also having a shading effect on the occupied spaces, thus reducing energy requirements for cooling. Also in this case, positioned peripherally, the service core allows for natural ventilation, thereby diminishing the total volume to be mechanically conditioned. Additional advantages include access to daylight into the service areas, making the building safer in case of power failure, and eliminating the need for mechanical pressurization ducts for fire-protection.

There are also other factors such as space allocation, circulation patterns, flexibility of space divisions, security, as well as specifications and building codes, together with the variety of their possible constraints. In the case of tall office buildings, the peripheral core provides the advantage of homogeneous workplaces, which is usually organized into one space, but demonstrates poor efficiency in terms of space use due to the extended circulation routes. In addition, the effective implementation of this configuration on large floor plates is challenging since the permissible distance from the furthest corner of the space to the fire escape is a limitation.

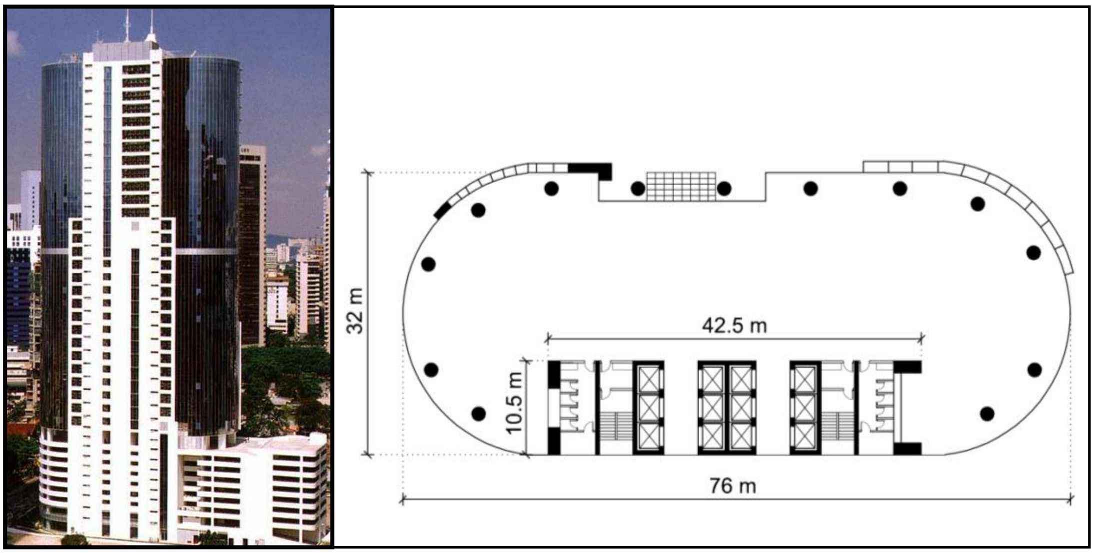


Figure 4.14 Menara Ta1, Hong Kong, China, 1989 (Drawing by Zeynep Keskin, image source: Yeang,2000)

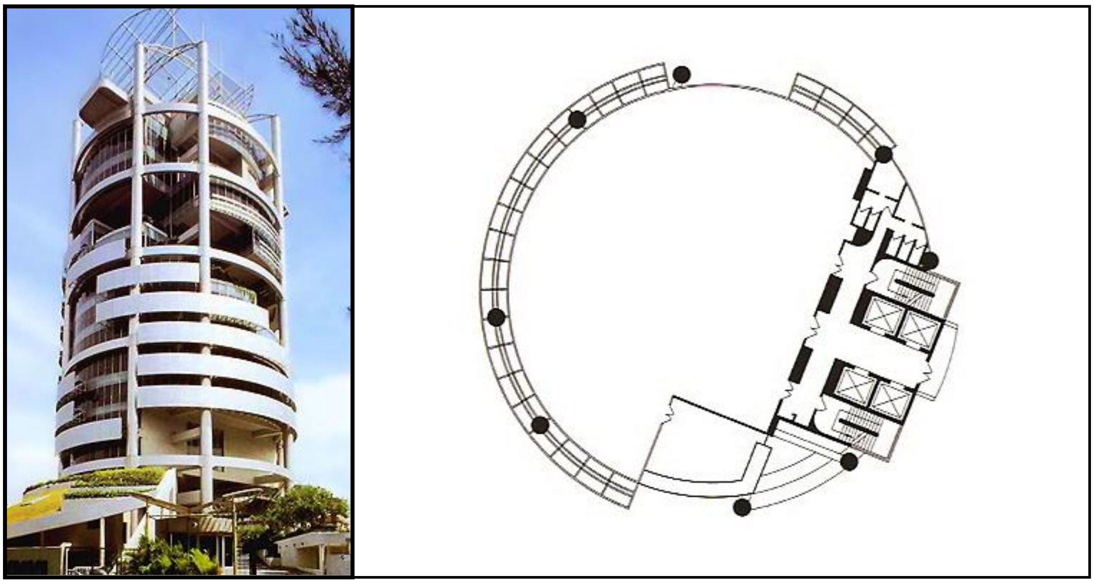
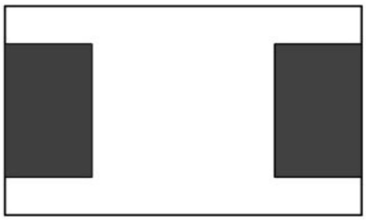


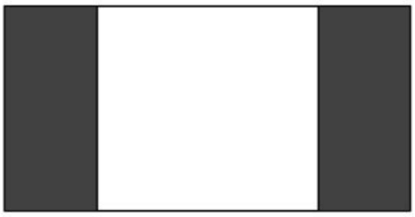
Figure 4.15 Menara Mesiniaga, Kuala Lumpur, Malaysia, 1992 (image source: Yeang,2000)

4.3.3 General Characteristics of Peripheral Split Cores:

The peripheral split core configuration is characterized by the division of the peripheral core into two or more elements in order to accommodate special design considerations for large or long-narrow floor plates where the single service core becomes insufficient to serve the entire floor plate (Figure 4.16). Such an arrangement allows for easy access by reducing the corridor length although the number of service increases and the service system becomes much more complex compared to the single core where the services are concentrated in the floor plate.



(a)



(b)

Figure 4.16 Peripheral Split Core Configuration

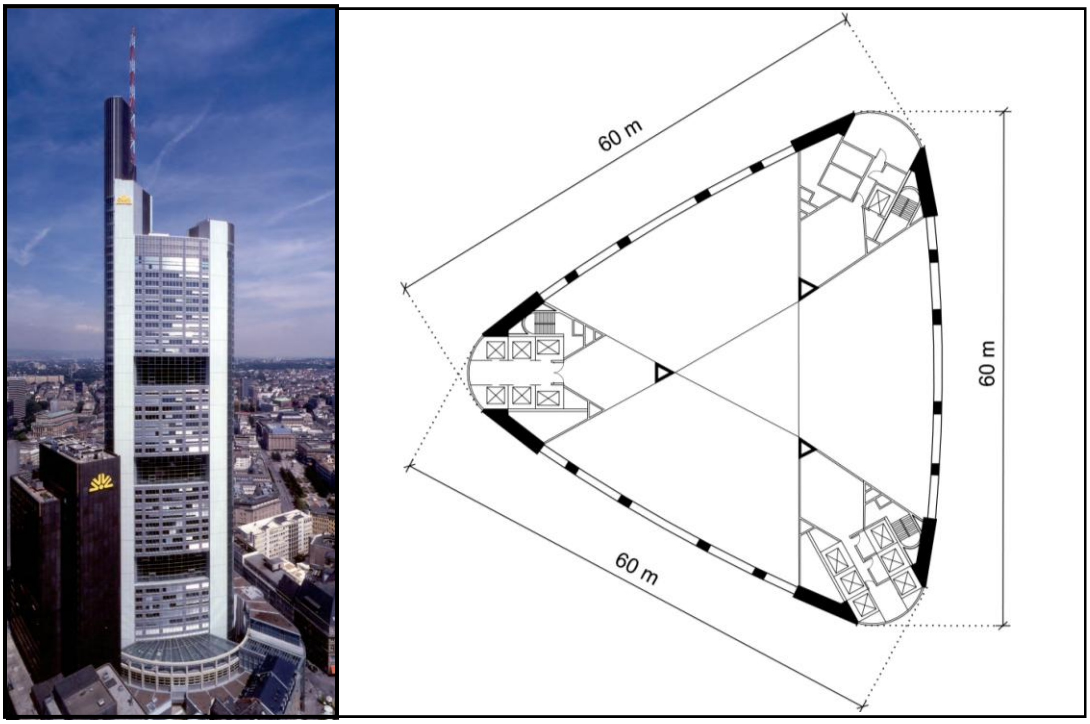
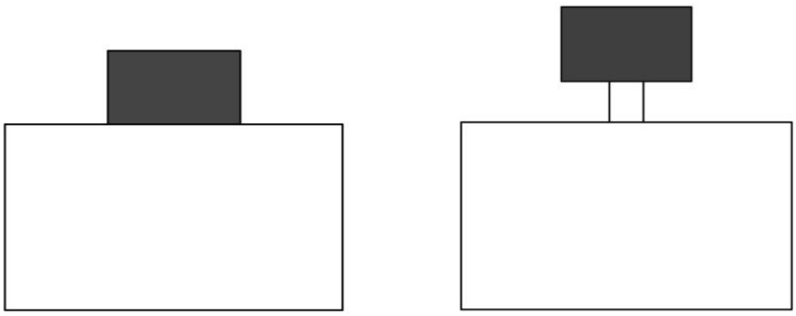


Figure 4.17 Commerzbank Tower, Frankfurt, Germany, 1997 (Drawing by Zeynep Keskin, image source: The Arup Journal,2/1997)

4.3.4 General Characteristics of External Cores:

The external core configuration consists of an independent core system in which it is isolated by constructing the core as a separate mass element either attached directly to the building or connected by sky bridges (Figure 4.18). In any particular case, the service core should necessarily be provided with an additional structural system so as to withstand its own weight as well as the lateral loads. Architecturally, the external core configuration differs from other core configurations in that the core is given conspicuous architectural treatment to be identified outside of the building.



(a) (b)

Figure 4.18 External Core Configuration

The basis of the importance given to the external core configuration is established on the fact that it provides several advantages regarding environmental performance of the building. The efficiency of this configuration is mainly derived from the shading effect on the building, natural lighting, and natural ventilation or from the idea that the solid structure of the core act as a thermal buffer and delay the heat gain of solar radiation. External cores allow greater daylight to reach the area of occupancy while also providing a valuable option in those climates where natural ventilation is viable for most of the year. An external naturally ventilated service core eliminates the need of air conditioning, thereby diminishing the total volume to be mechanically conditioned.

Besides its advantages, external core configuration has several drawbacks which inherently limits the functionality and create problems in the organization of internal space and traffic as well as in accessibility during emergencies as in the case of peripheral core configuration. As an independently constructed building element, the external core presents functional challenges especially since its location in the floor plan causes the area of occupancy to be sited at a considerable distance from the service areas and thus adversely affects accessibility. Also in this case, the service core requires longer corridors and sky bridges to be connected with the main building, which results in decreased floor plan efficiency. In addition, the increased perimeter of the building requires higher quantities of material for cladding.

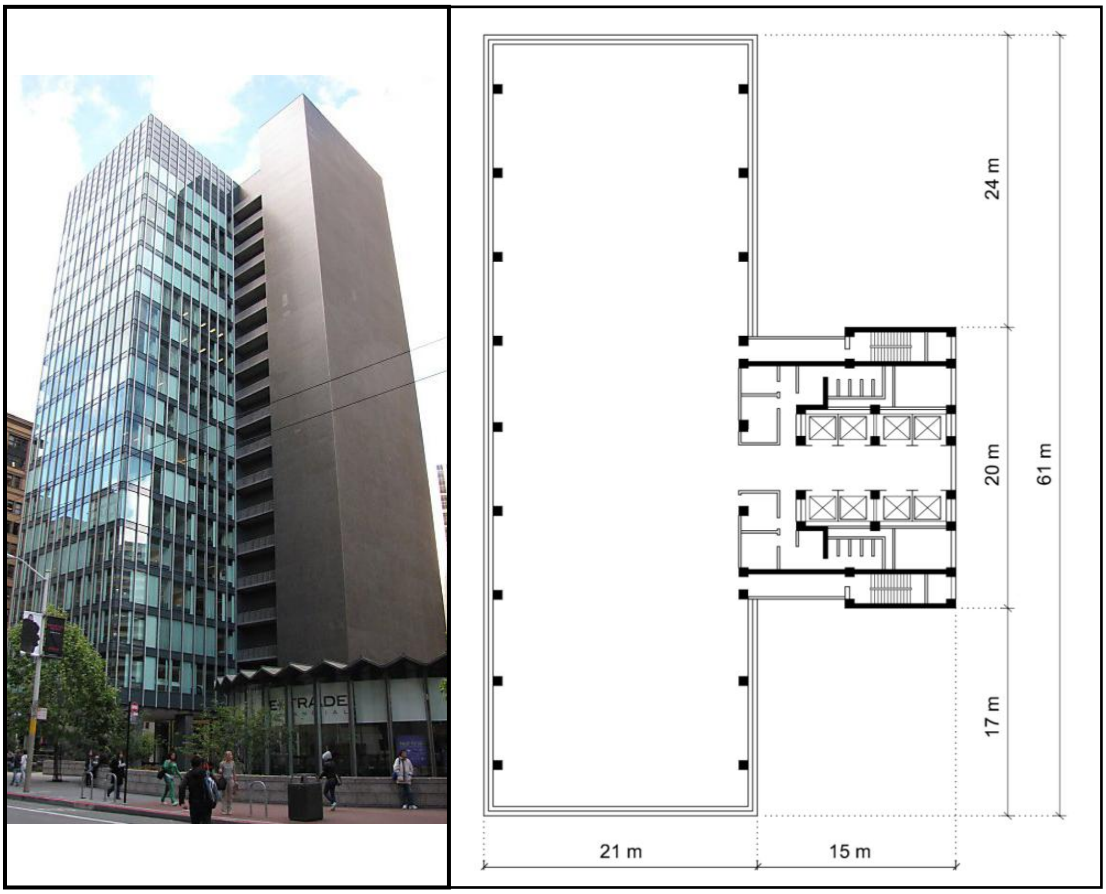


Figure 4.19 One Bush Plaza, San Francisco, USA (Drawing by Zeynep Keskin, image source: www.som.com)

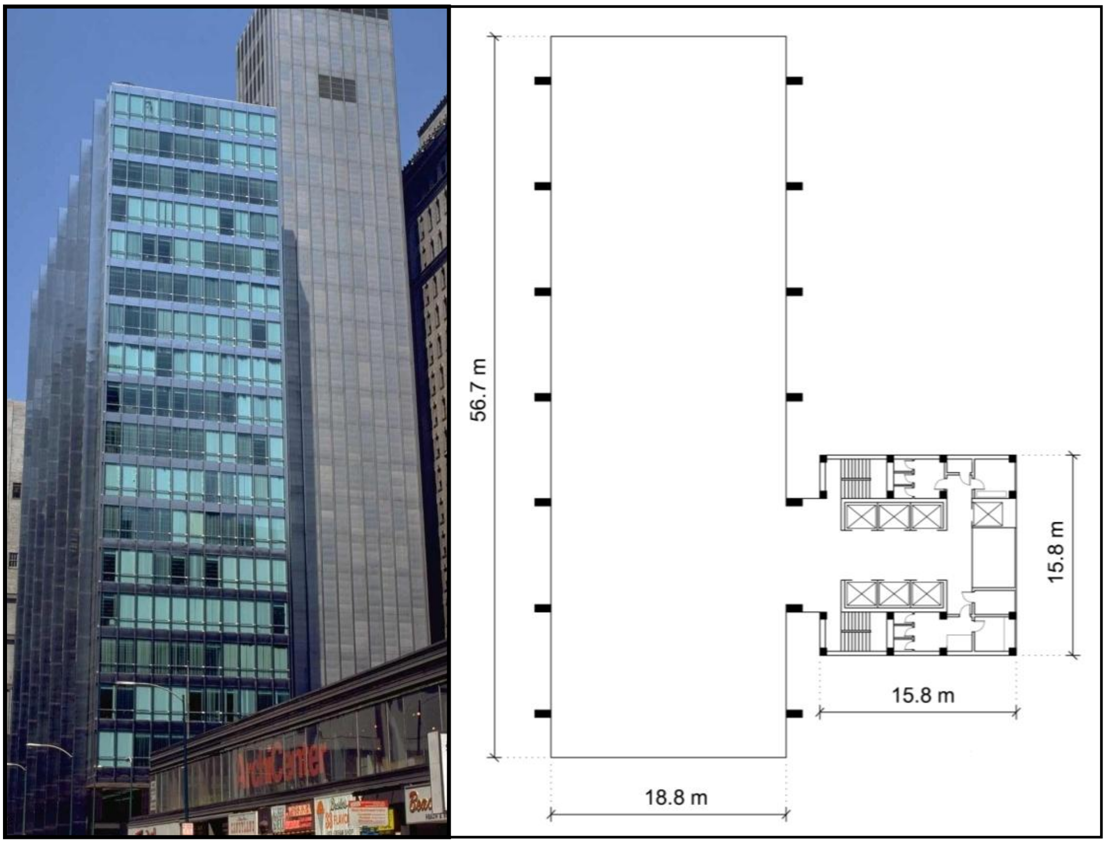
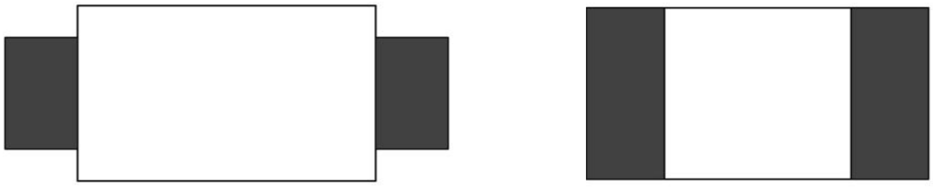


Figure 4.20 Inland Steel Building, Chicago, Illionis (Drawing by Zeynep Keskin, image source: http://www.learn.columbia.edu)

4.3.5 General Characteristics of External Split Cores:

External split core configuration is characterized by the division of the external core into two or more elements since the single core is not sufficient to serve the entire floor plate in the case of large or long-narrow floor plates, suffering similar limitations to those outlined above for the peripheral core configuration (Figure 4.21). In addition, this configuration can be particularly useful when considering the shading requirements on a building or the solar radiation over the surfaces of an entire building.



(a) (b)

Figure 4.21 External Split Core Configuration

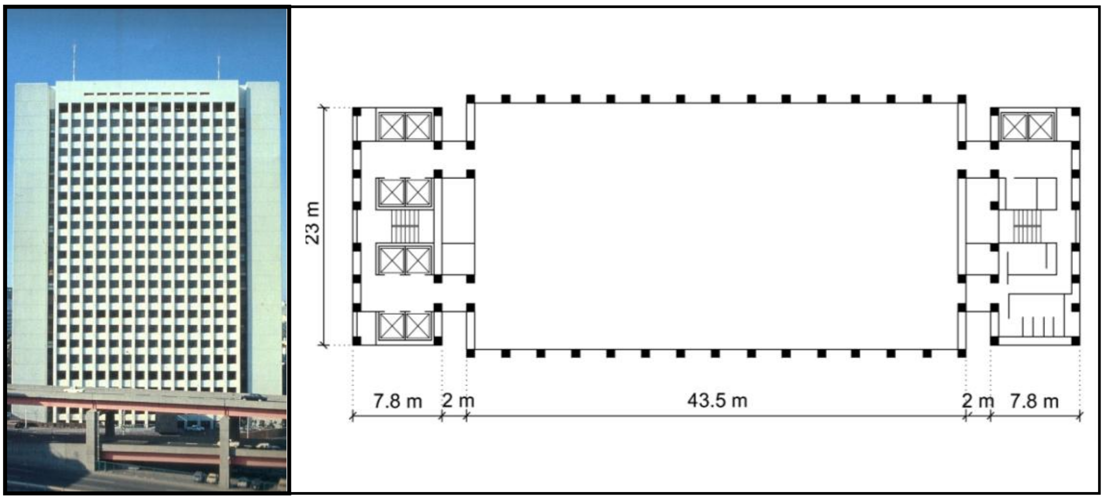


Figure 4.22 IBM Headquarters Building, Tokyo, Japan (Drawing by Zeynep Keskin, image source: Yeang, 2000)

4.3.6 General Characteristics of Atrium Cores:

One of the most effective ways to improve the environment for occupants is to create atriums involving large glazing surfaces in which natural lighting and air movement are given preference. The atrium core, generally located in the central position, attempts to combine the benefits of external and peripheral core configurations such as natural ventilation and lighting to the case of central core configuration (Figure 4.23). In other words, it attempts to improve the effectiveness of the central core configuration by the help of atrium so that greater freedom in the use of open space can be achieved even in the central core configuration. Thus, this configuration can be considered as a modified form of central core configuration. The incorporation of an atrium into a tall building can save energy by provision of daylight into the occupied spaces, forming a buffer zone between indoor and outdoor environment and providing natural ventilation. However, it is important to note that the fire control is an important aspect of atrium core design since the atrium could allow fire to spread to the upper floors more quickly by creating the chimney effect.

The atrium core configuration can be divided into two or more elements, which is considerably more desirable than the single atrium core configuration in the case of large or long-narrow floor plates (Figure 4.24). In such buildings there is a possibility of visually interconnecting floors through the use of atrium and the potential to increase the number of service in the floor plate and allow for easy access.

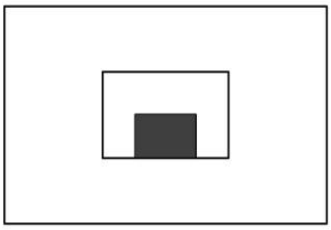


Figure 4.23 Atrium Core Configuration

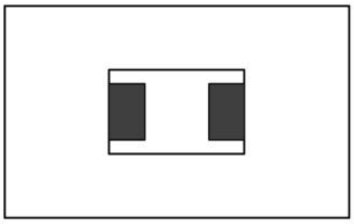


Figure 4.24 Atrium Split Core Configuration

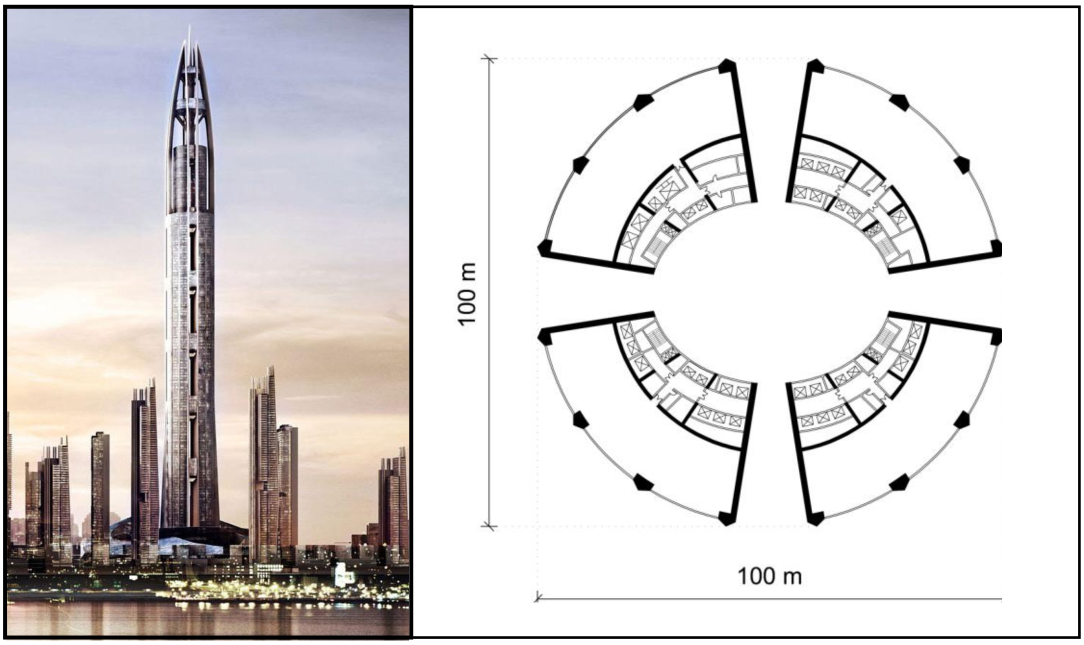


Figure 4.25 Nakheel Tower, Dubai, United Arab Emirates (Drawing by Zeynep Keskin, image source: worldarchitecturenews.com)

CHAPTER 5

CASE STUDIES

In the frame of this study, to conclude and bring together the proposals, case study examples were examined; analyzing some of the relevant facets enumerated above by reviewing these projects according to their service core configuration. For this purpose, 20 tallest buildings were investigated. All the measurements are based on acquired architectural drawings though the difficulty of collecting data has experienced due to security issues of tall buildings. Based on the results of the case studies, a set of quantitative analysis was performed to show the relationship among service core implications.

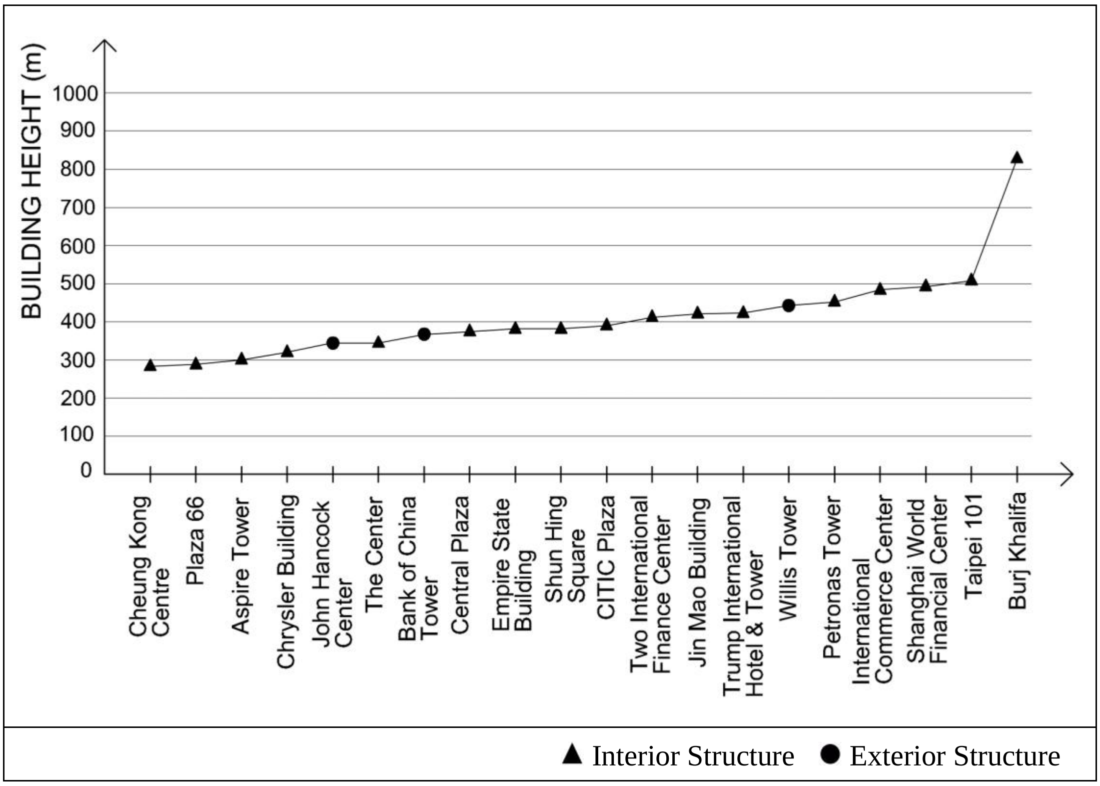


Figure 5.1 Comparative heights and structural systems of several of the world's tallest buildings

5.1 Burj Khalifa, Dubai, United Arab Emirates, 2010

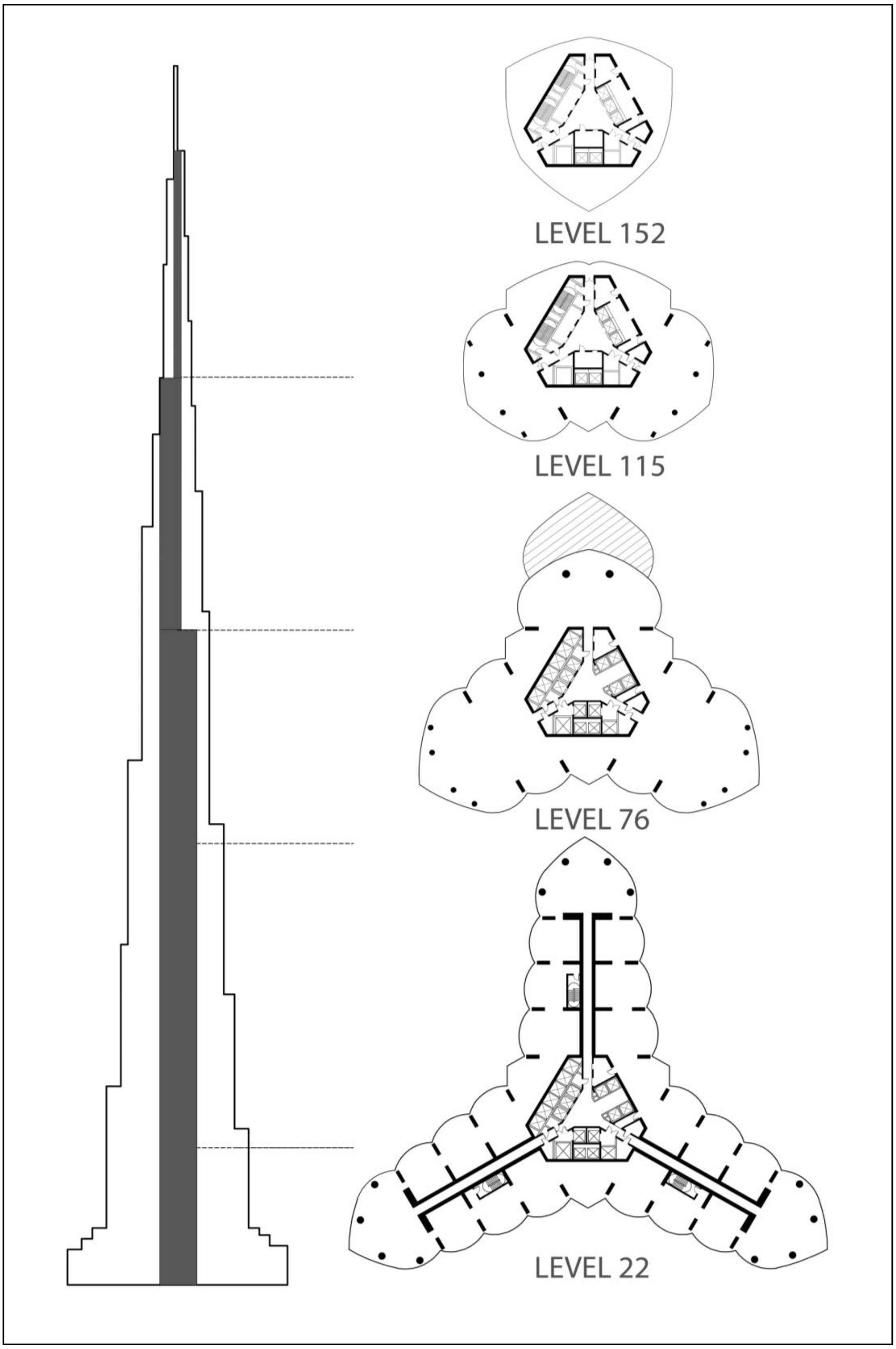


Figure 5.2 Section and floor plans of Burj Khalifa (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Dubai
HEIGHT	**:** 828 m
FLOORS	**:** 163
FUNCTION	**:** Office/Residential/Hotel
CONSTRUCTION DATE	**:** 2010
ARCHITECT	**:** Adrian Smith & SOM
STRUCTURAL MATERIAL	**:** Steel-Concrete
ELEVATORS	**:** 58
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA	**:** 404 m²
TYPICAL FLOOR AREA	**:** 4645 m²

Figure 5.3 General Information (source: CTBUH)

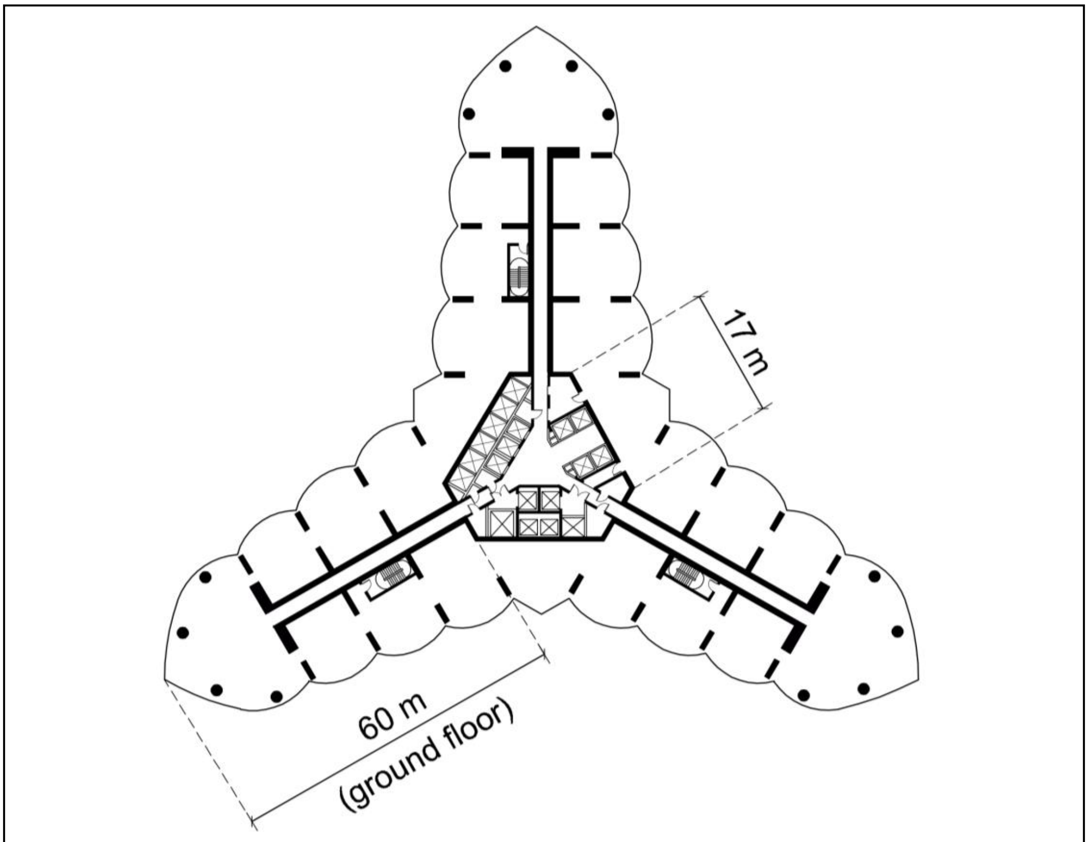


Figure 5.4 Typical Floor Plan

5.2 Taipei 101, Taipei, Taiwan, 2004

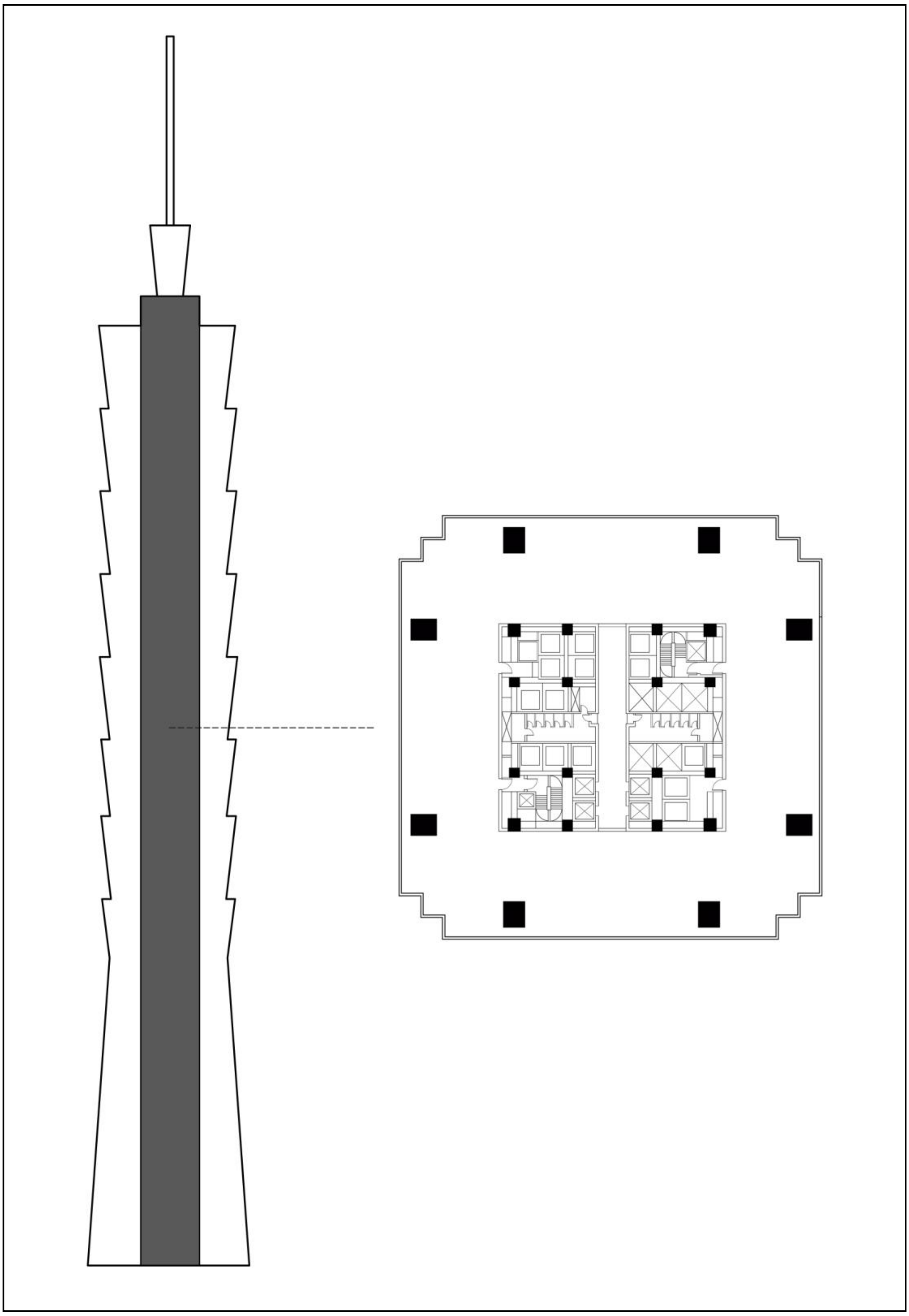


Figure 5.5 Section and floor plan of Taipei 101 (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Taipei
HEIGHT	**:** 508 m
FLOORS	**:** 101
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 2004
ARCHITECT	**:** C.Y. Lee & partners
STRUCTURAL MATERIAL : Composite	
ELEVATORS	**:** 67
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 506 m²	
TYPICAL FLOOR AREA : 2043 m²	

Figure 5.6 General Information (source: CTBUH)

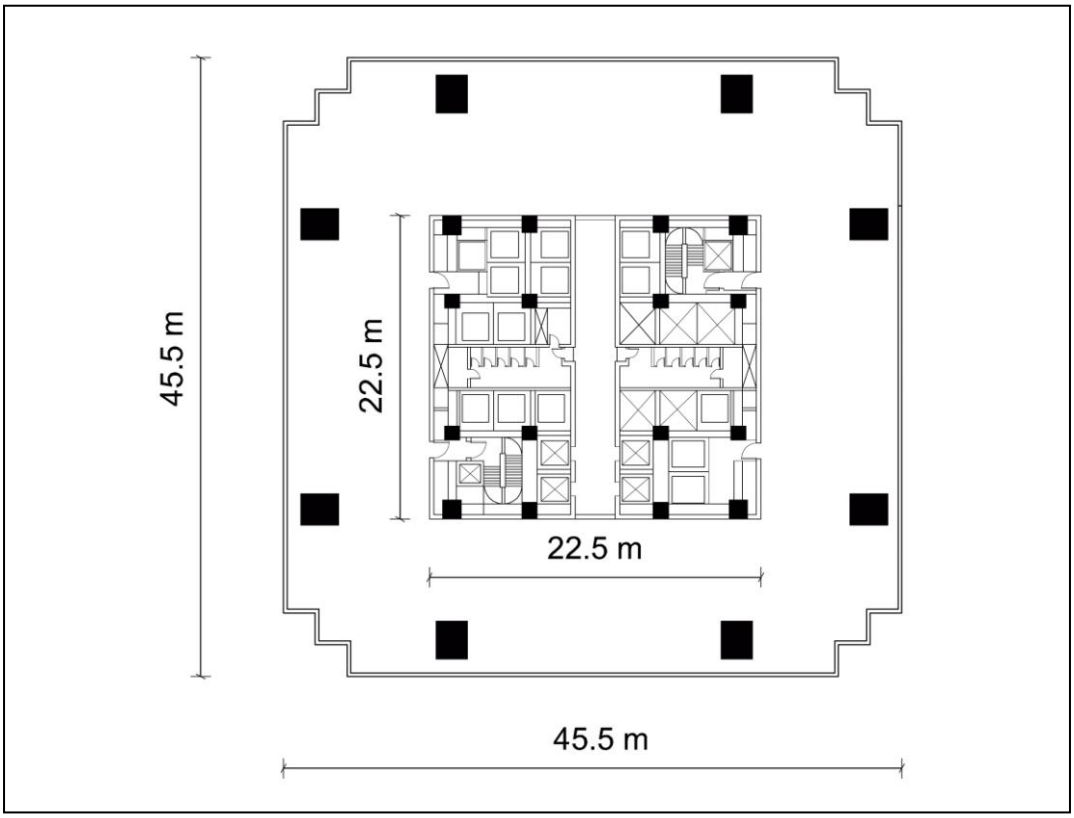


Figure 5.7 Typical Floor Plan

5.3 Shanghai World Financial Center, Shanghai, China, 2008

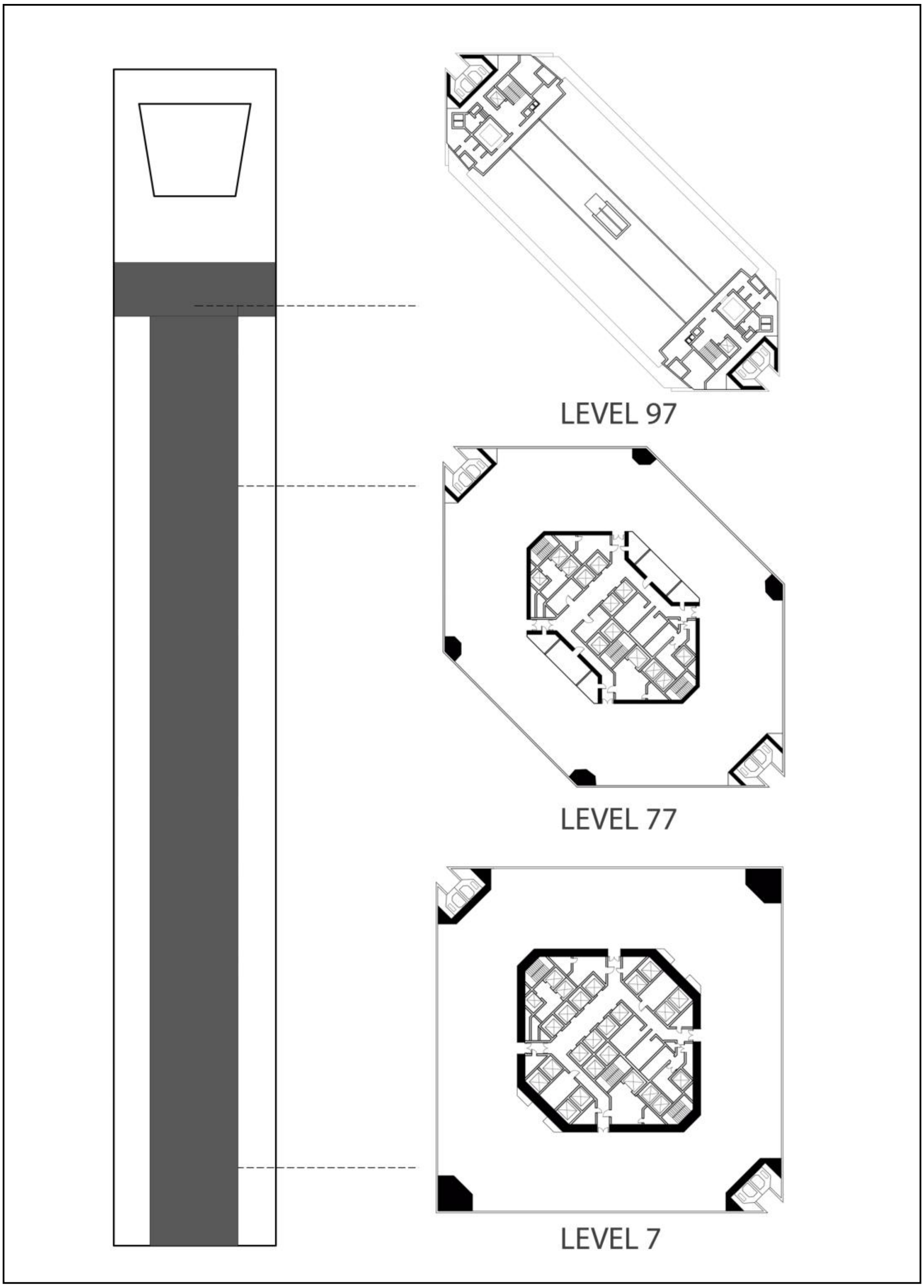


Figure 5.8 Section and floor plans of Shanghai World Financial Center (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Shanghai
HEIGHT	**:** 492 m
FLOORS	**:** 101
FUNCTION	**:** Office/Hotel
CONSTRUCTION DATE	**:** 2008
ARCHITECT	**:** Kohn Pederson Fox
STRUCTURAL MATERIAL : Composite	
ELEVATORS	**:** 31
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 951 m²	
TYPICAL FLOOR AREA : 3364 m²	

Figure 5.9 General Information (source: CTBUH)

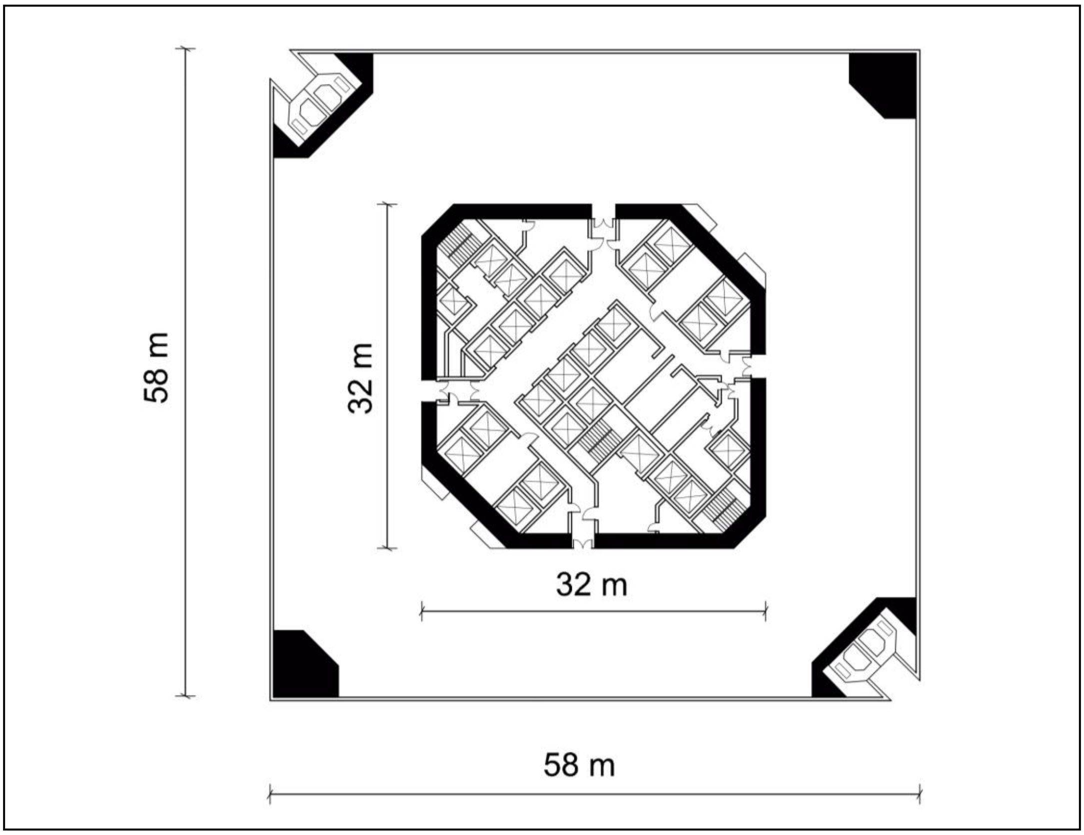


Figure 5.10 Typical Floor Plan

5.4 International Commerce Center, Hong Kong, China, 2010

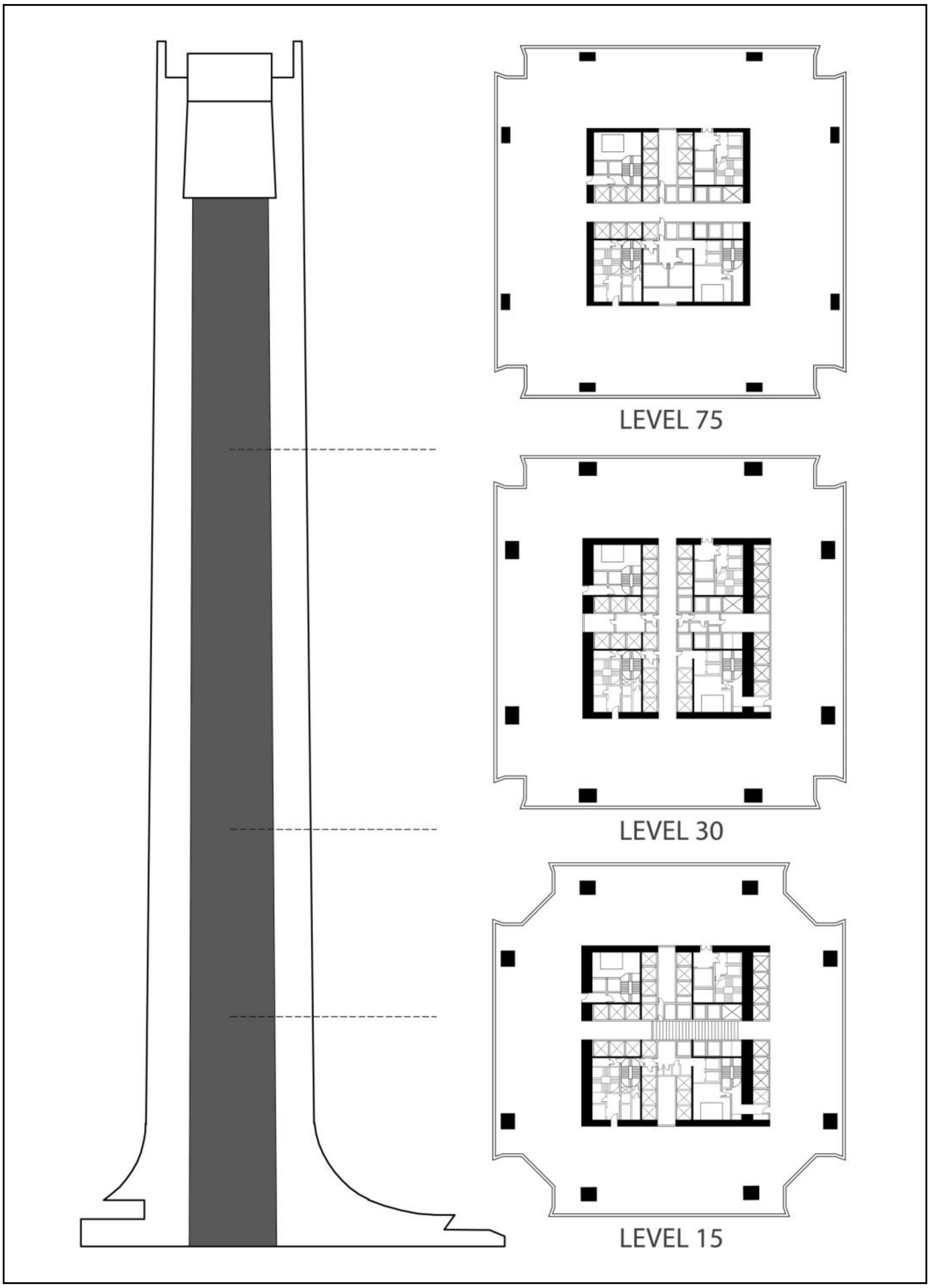


Figure 5.11 Section and floor plans of ICC (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Hong Kong
HEIGHT	**:** 484 m
FLOORS	**:** 108
FUNCTION	**:** Office/Hotel
CONSTRUCTION DATE	**:** 2010
ARCHITECT	**:** Kohn Pederson Fox
STRUCTURAL MATERIAL	**:** Composite
ELEVATORS	**:** 83
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 1132 m²	
TYPICAL FLOOR AREA : 3807 m²	

Figure 5.12 General Information (source: CTBUH)

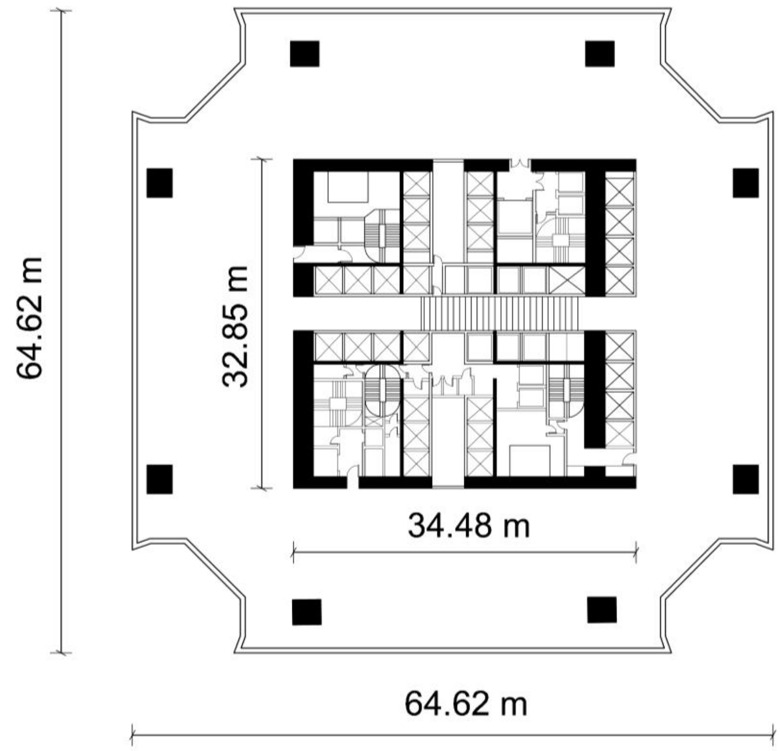


Figure 5.13 Typical Floor Plan

5.5 Petronas Tower, Kuala Lumpur, Malaysia, 1998

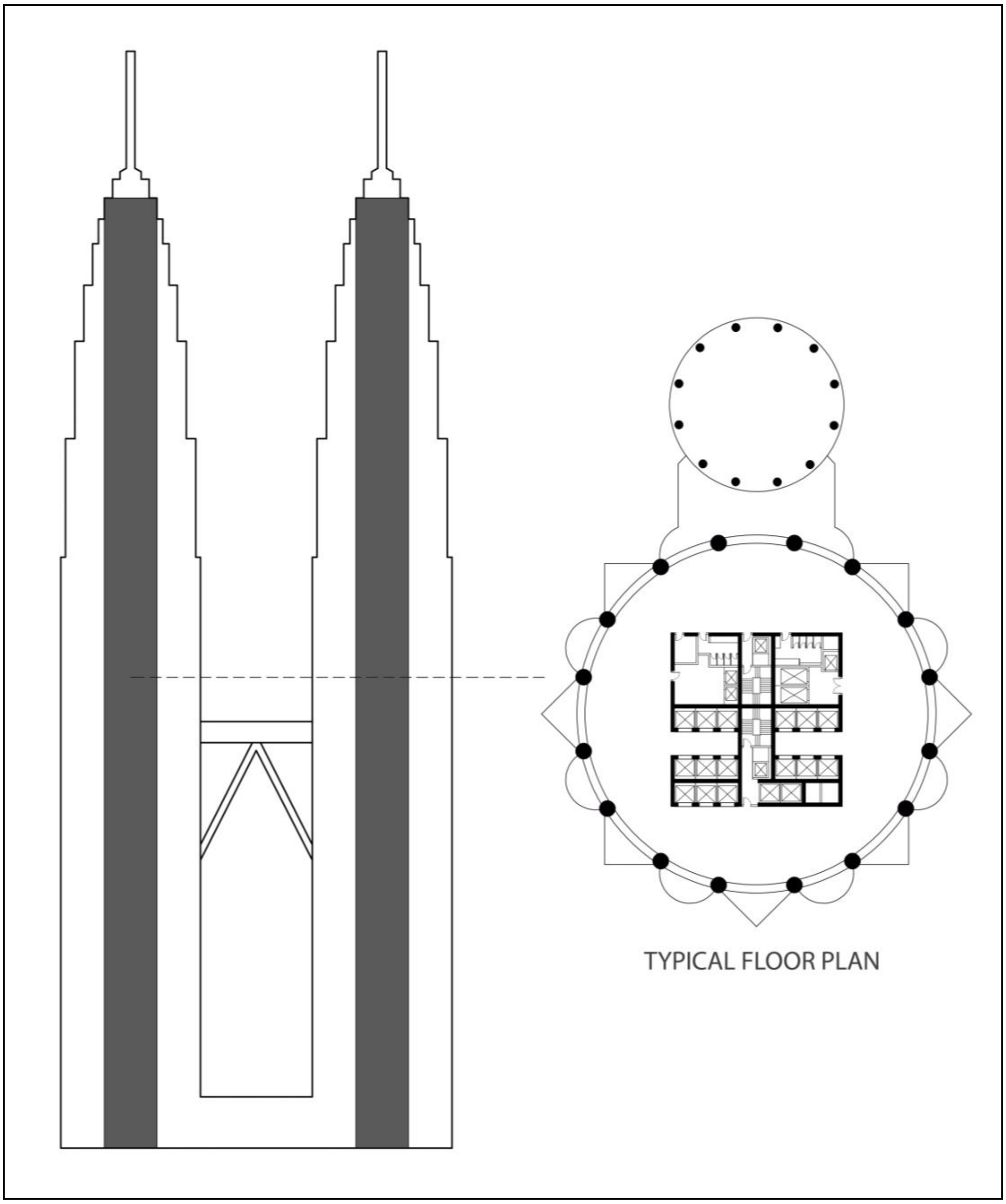


Figure 5.14 Section and floor plan of Petronas Tower (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Malaysia
HEIGHT	**:** 452 m
FLOORS	**:** 88
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 1998
ARCHITECT	**:** Cesar Pelli
STRUCTURAL MATERIAL	**:** Composite
ELEVATORS	**:** 78
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 462 m²	
TYPICAL FLOOR AREA : 2144 m²	

Figure 5.15 General Information (source: CTBUH)

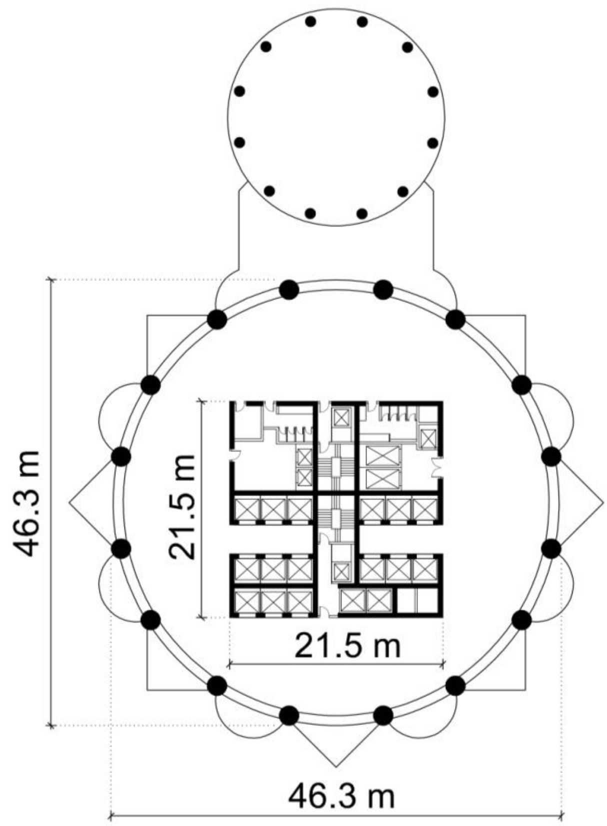


Figure 5.16 Typical Floor Plan

5.6 Willis Tower, Chicago, USA, 1974

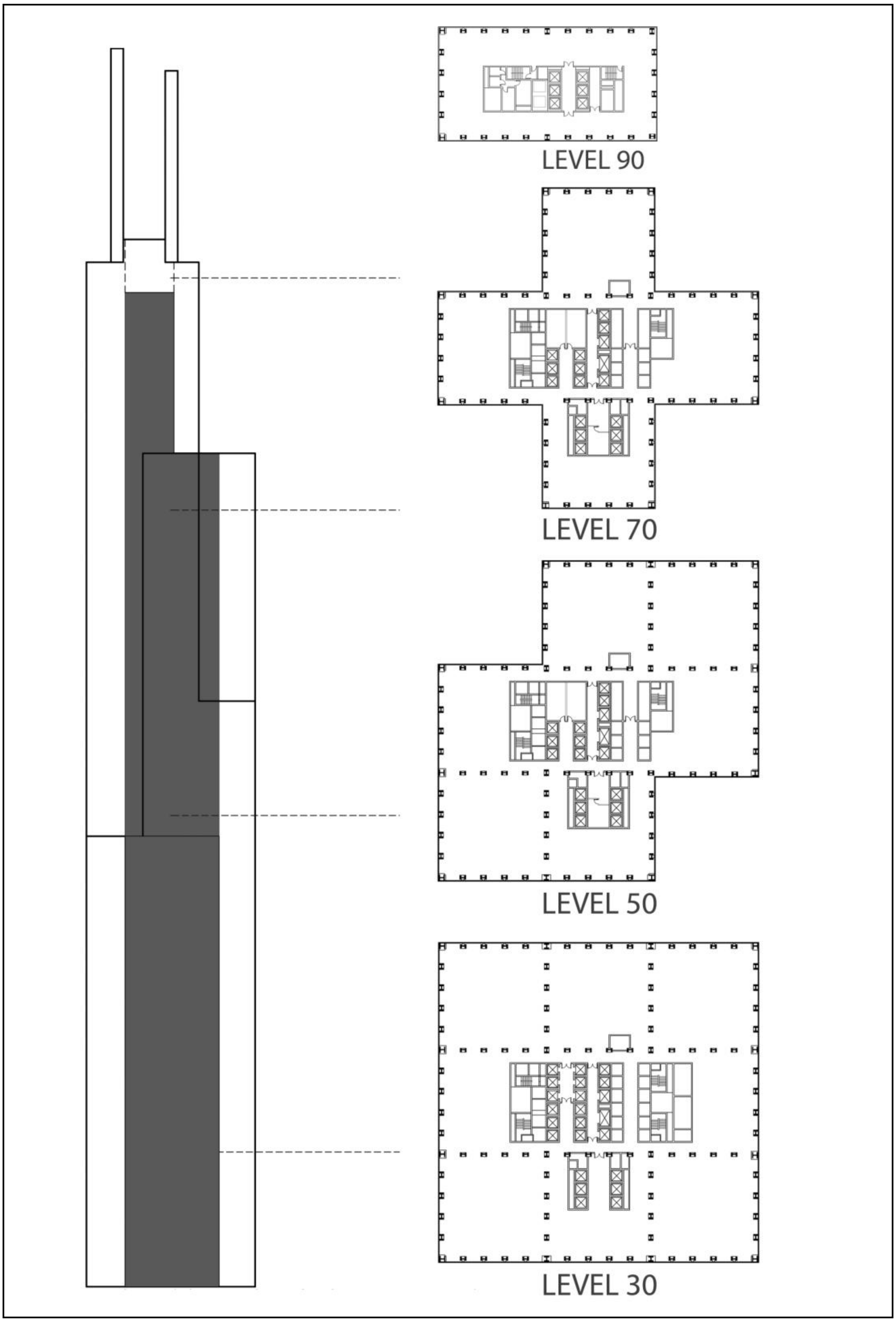


Figure 5.17 Section and floor plans of Willis Tower (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Chicago
HEIGHT	**:** 442 m
FLOORS	**:** 108
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 1974
ARCHITECT	**:** SOM
STRUCTURAL MATERIAL : Steel	
ELEVATORS	**:** 104
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 903 m²	
TYPICAL FLOOR AREA : 4720 m²	

Figure 5.18 General Information (source: CTBUH)

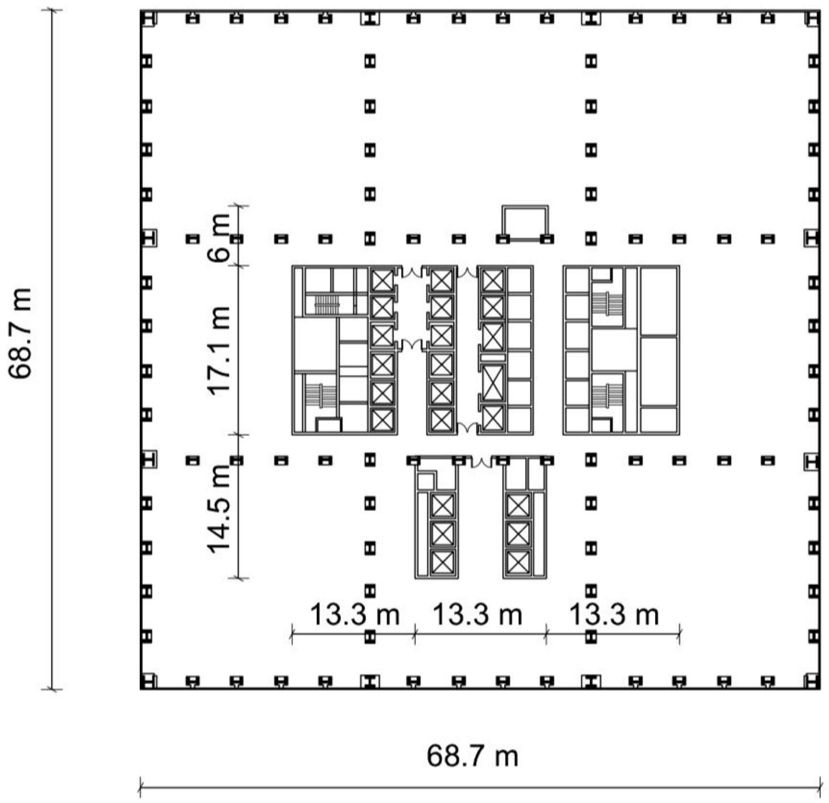


Figure 5.19 Typical Floor Plan

5.7 Trump International Hotel&Tower, Chicago, USA, 2009

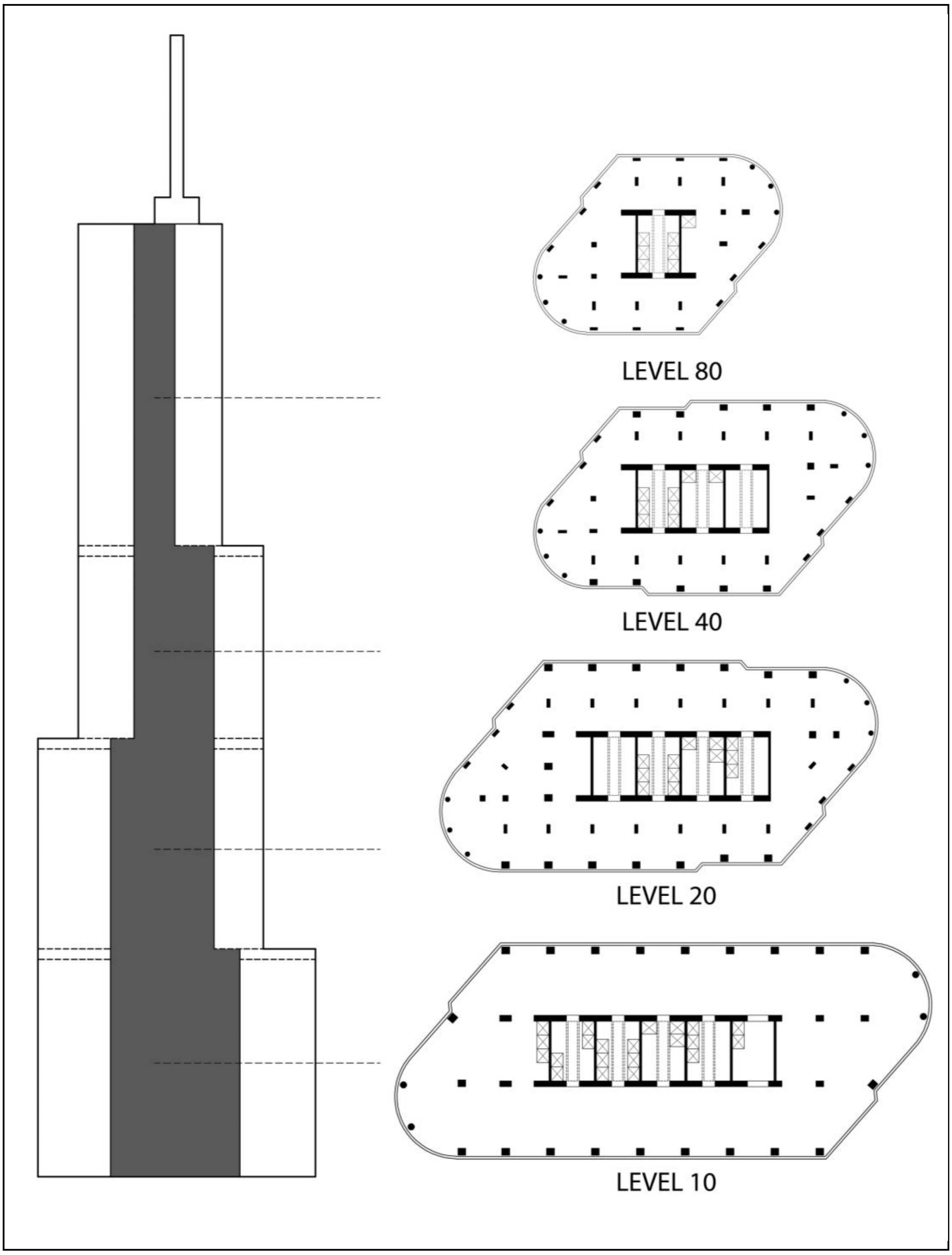


Figure 5.20 Section and floor plans of Trump Tower (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Chicago
HEIGHT	**:** 423 m
FLOORS	**:** 98
FUNCTION	**:** Hotel/Residential
CONSTRUCTION DATE	**:** 2009
ARCHITECT	**:** SOM
STRUCTURAL MATERIAL	**:** Concrete
ELEVATORS	**:** 27
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA	**:** 820 m²
TYPICAL FLOOR AREA	**:** 3410 m²

Figure 5.21 General Information (source: CTBUH)

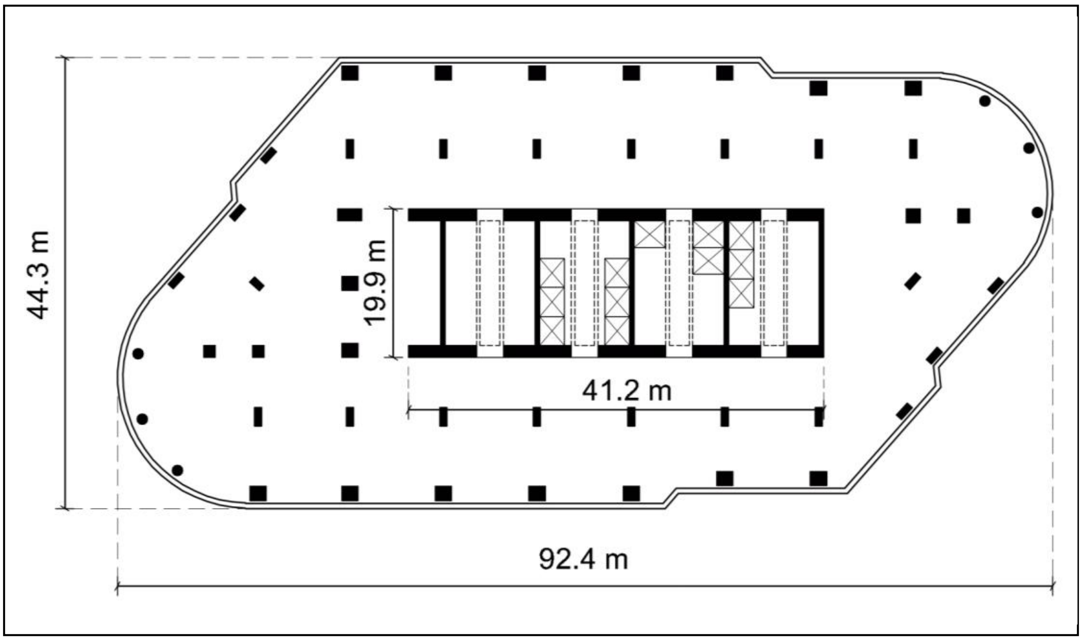


Figure 5.22 Typical Floor Plan (Drawing by Zeynep Keskin)

5.8 Jin Mao Building, Shanghai, China, 1999

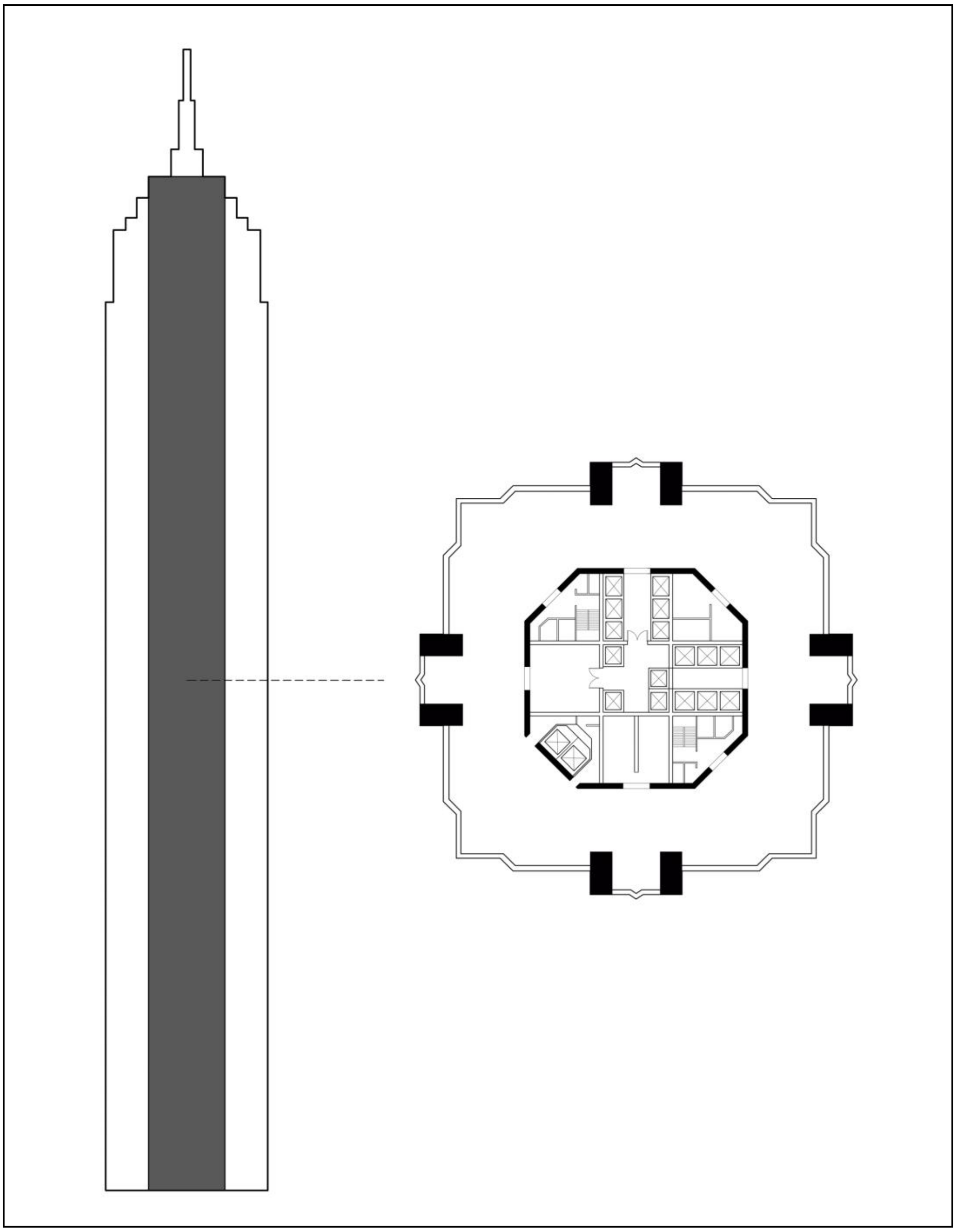


Figure 5.23 Section and floor plan of Jin Mao Building

(Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Shanghai
HEIGHT	**:** 421 m
FLOORS	**:** 88
FUNCTION	**:** Office/Hotel
CONSTRUCTION DATE	**:** 1999
ARCHITECT	**:** SOM
STRUCTURAL MATERIAL : Composite	
ELEVATORS	**:** 61
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 668 m²	
TYPICAL FLOOR AREA : 2600 m²	

Figure 5.24 General Information (source: CTBUH)

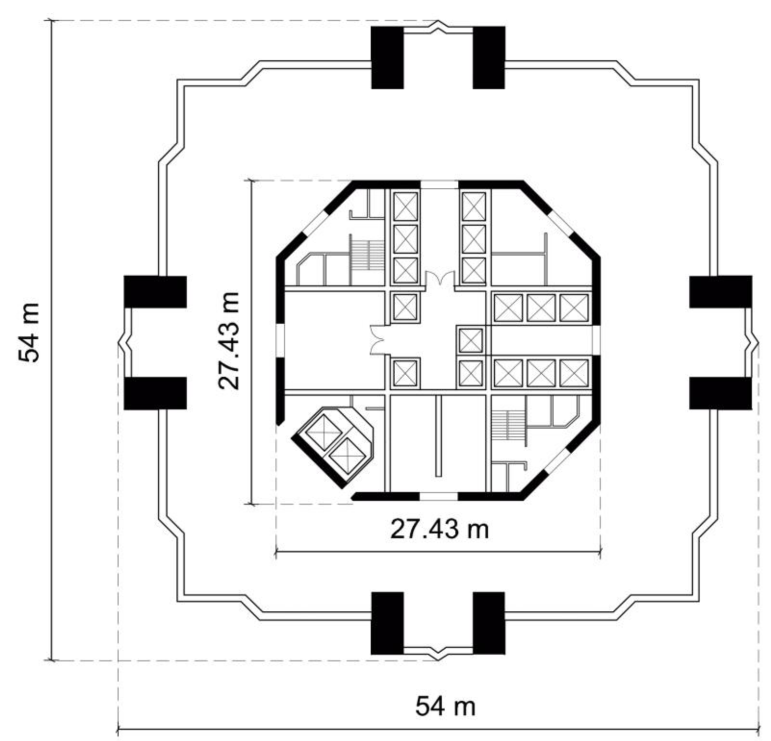


Figure 5.25 Typical Floor Plan

5.9 Two International Finance Center, Hong Kong, China, 2003

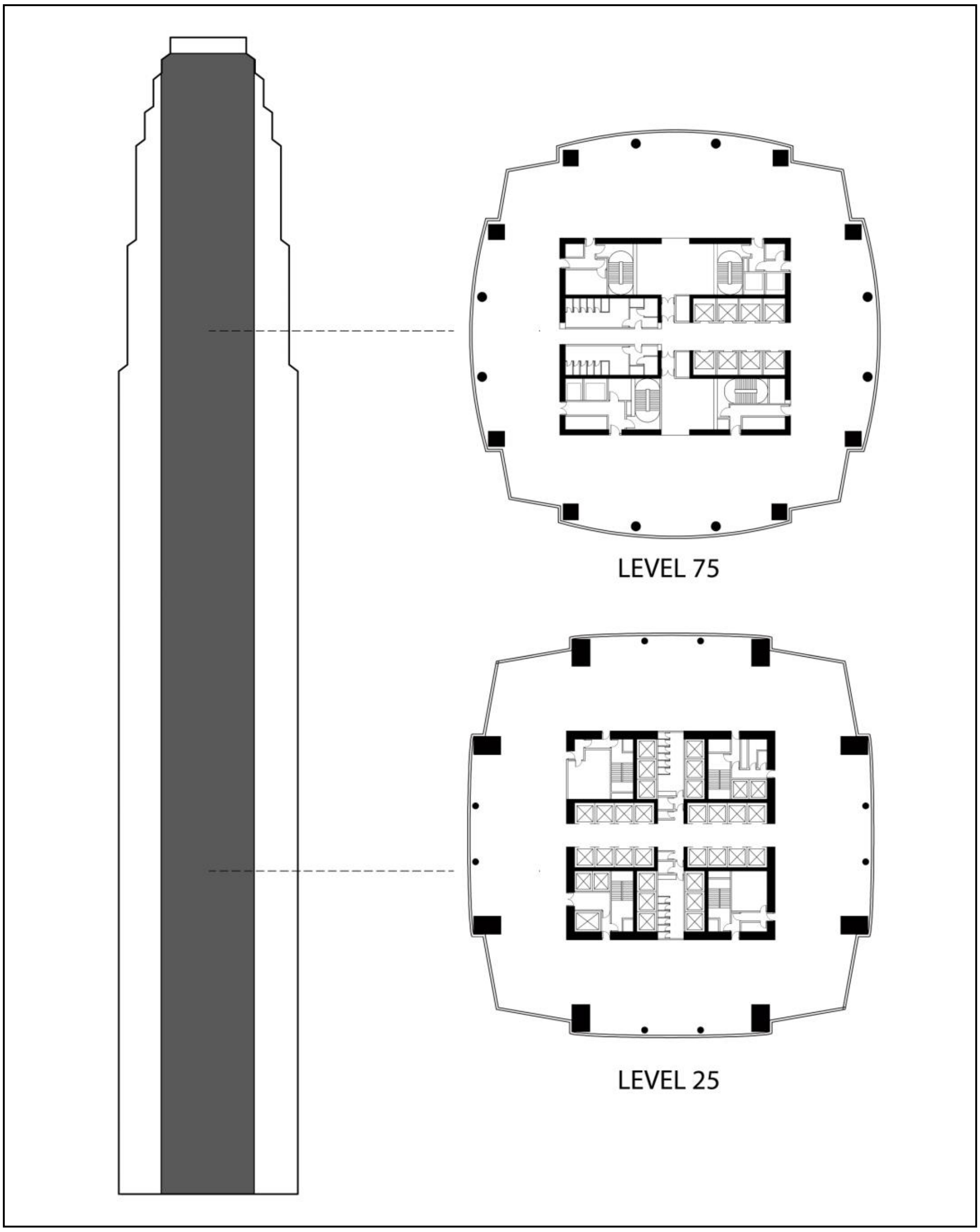


Figure 5.26 Section and floor plans of Two International Finance Center
(Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Hong Kong
HEIGHT	**:** 412 m
FLOORS	**:** 88
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 2003
ARCHITECT	**:** Cesar Pelli&Assoc.
STRUCTURAL MATERIAL : Composite	
ELEVATORS	**:** 62
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 783 m²	
TYPICAL FLOOR AREA : 3240 m²	

Figure 5.27 General Information (source: CTBUH)

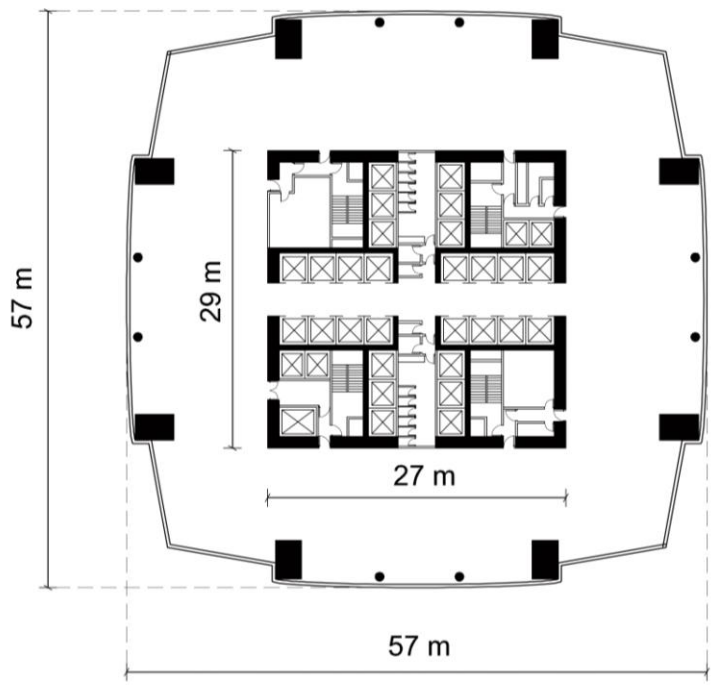


Figure 5.28 Typical Floor Plan

5.10 CITIC Plaza, Guangzhou, China, 1996

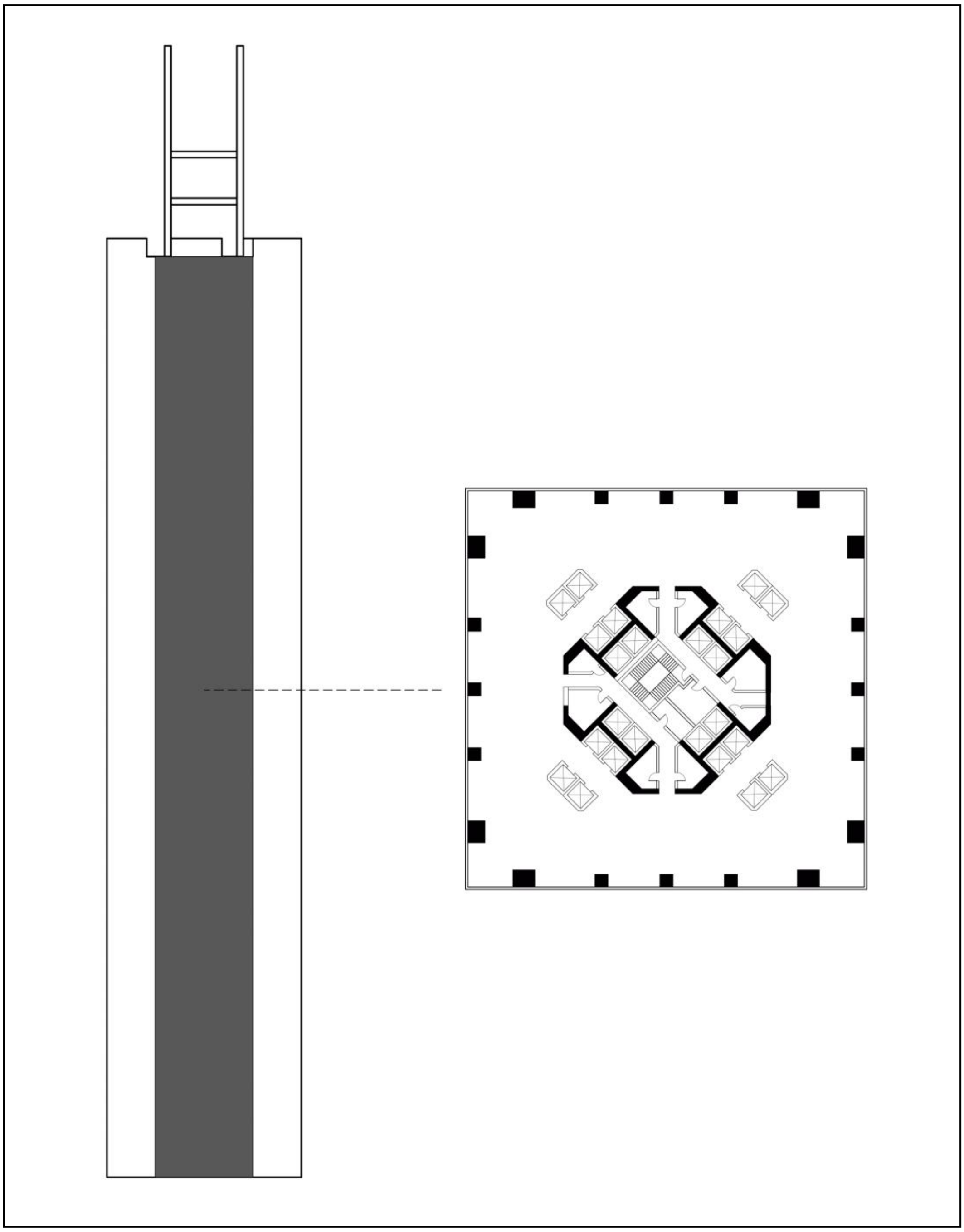


Figure 5.29 Section and floor plan of CITIC Plaza (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Guangzhou
HEIGHT	**:** 390 m
FLOORS	**:** 80
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 1996
ARCHITECT	**:**DLN Architects
STRUCTURAL MATERIAL : Concrete	
ELEVATORS	**:** 36
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 576 m²	
TYPICAL FLOOR AREA : 2230 m²	

Figure 5.30 General Information (source: CTBUH)

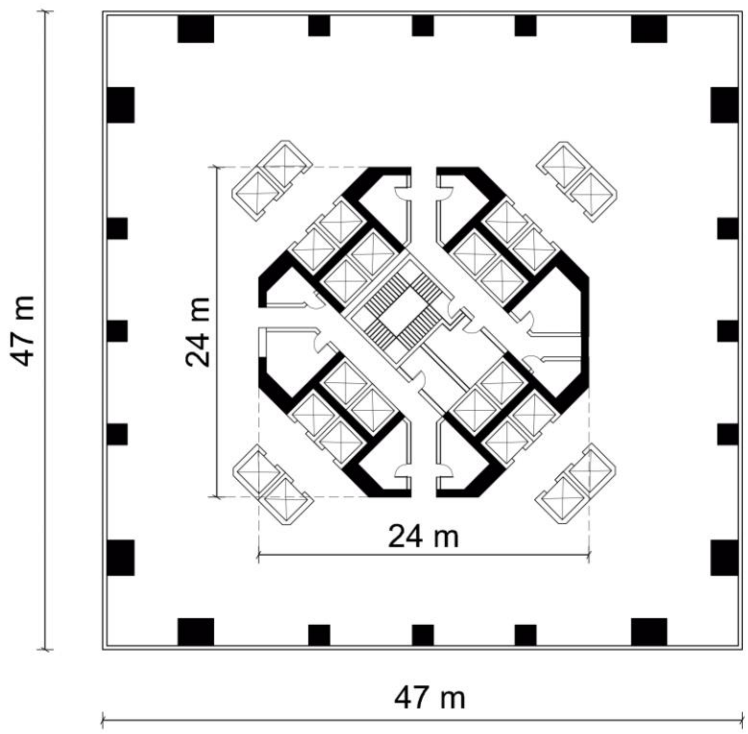


Figure 5.31 Typical Floor Plan

5.11 Shun Hing Square, Shenzhen, China, 1996

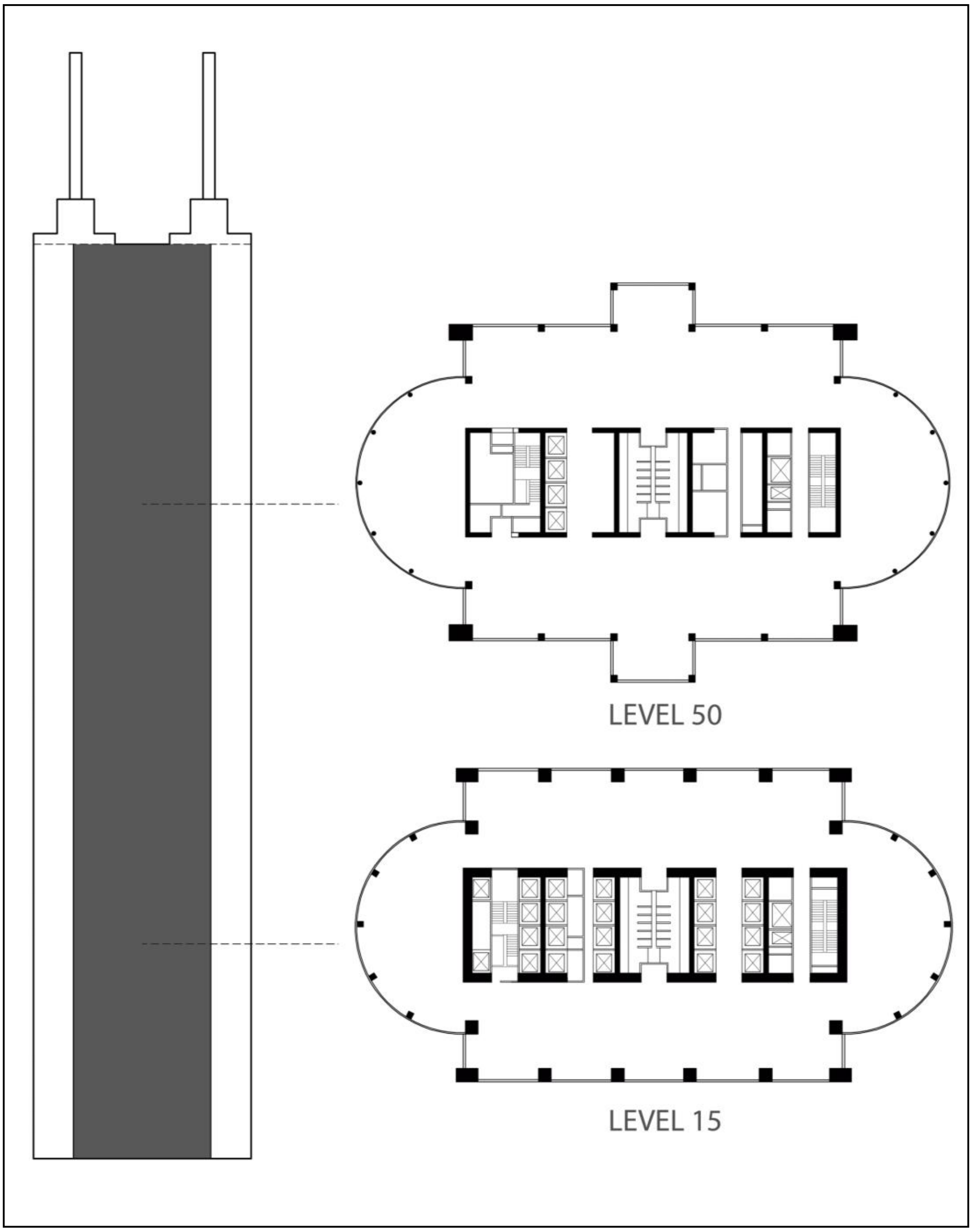


Figure 5.32 Section and floor plans of Shun Hing Square (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Shenzhen
HEIGHT	**:** 384 m
FLOORS	**:** 69
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 1996
ARCHITECT	**:** K.Y.Cheung Design
STRUCTURAL MATERIAL : Composite	
ELEVATORS	**:** 36
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 642 m²	
TYPICAL FLOOR AREA : 2078 m²	

Figure 5.33 General Information (source: CTBUH)

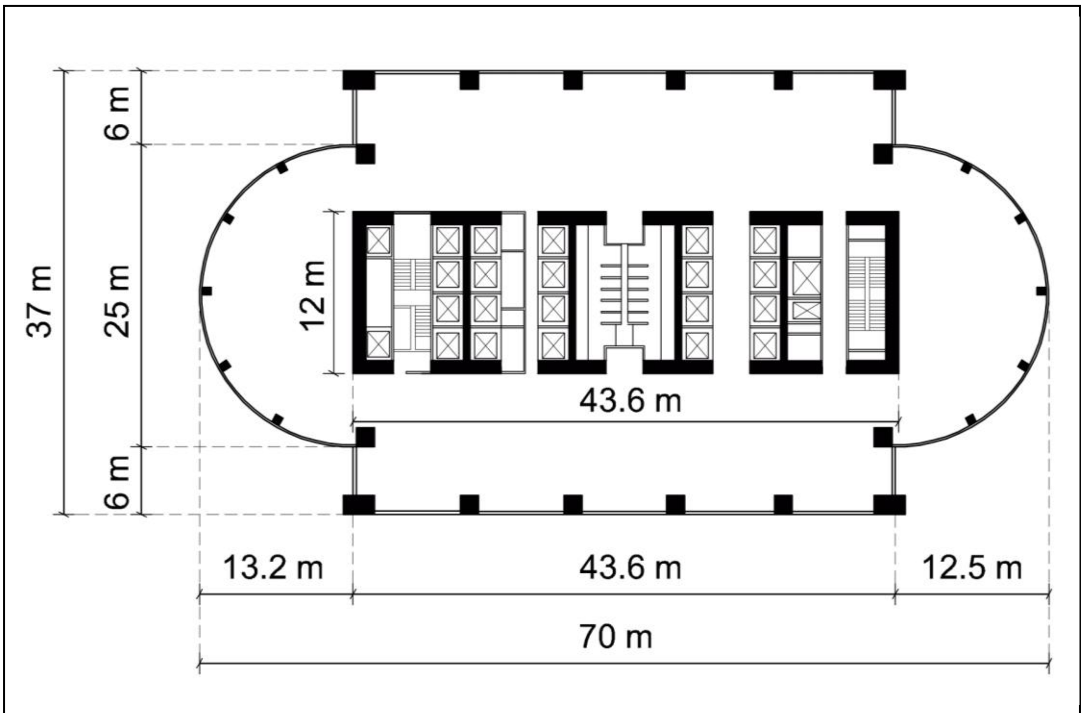


Figure 5.34 Typical Floor Plan

5.12 Empire State Building, New York, USA, 1931

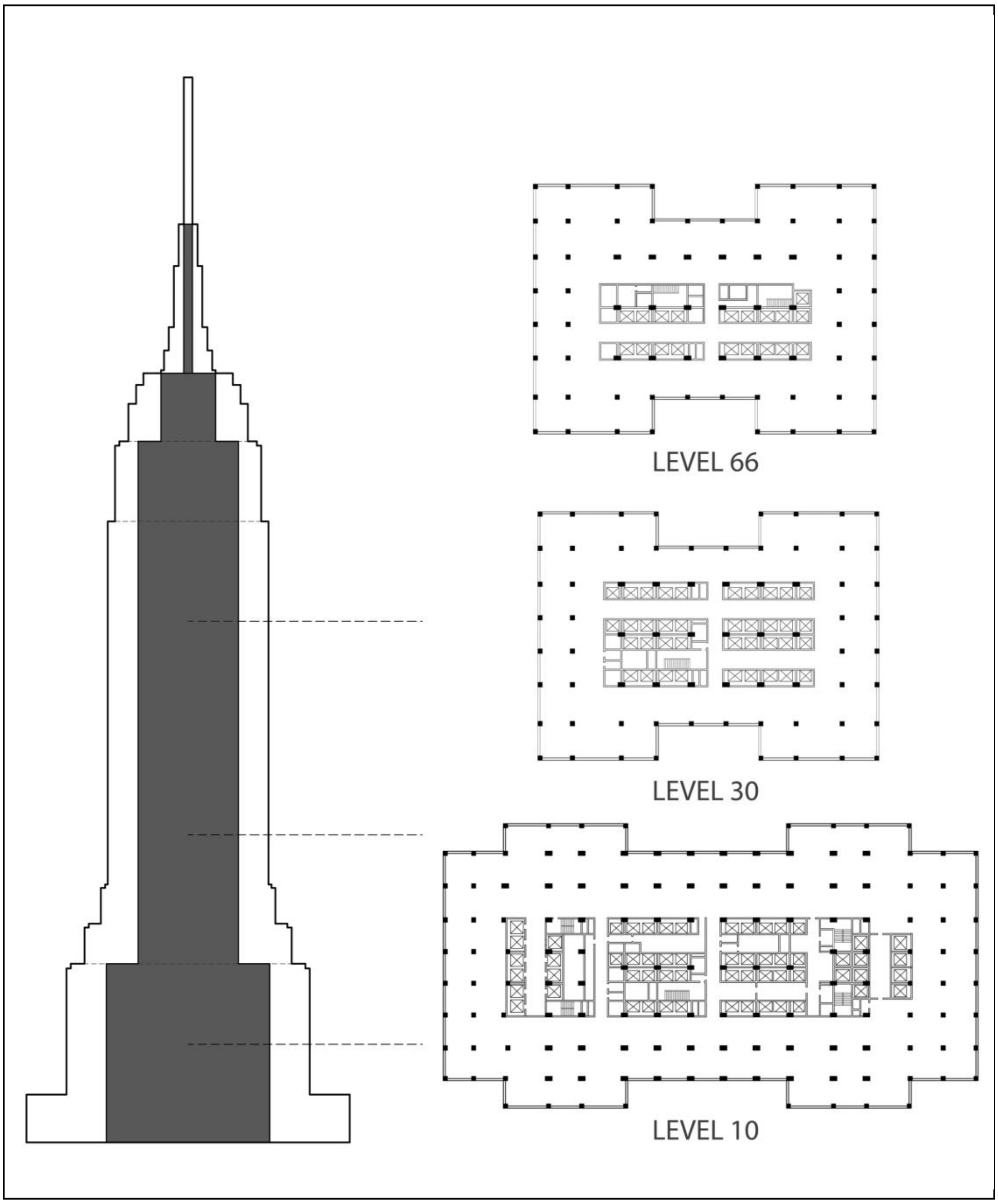


Figure 5.35 Section and floor plans of Empire State Building (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** New York
HEIGHT	**:** 381 m
FLOORS	**:** 102
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 1931
ARCHITECT	**:**Shreve,Lamb and Harmon
STRUCTURAL MATERIAL : Steel	
ELEVATORS	**:** 73
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 648 m²	
TYPICAL FLOOR AREA : 2415 m²	

Figure 5.36 General Information (source: CTBUH)

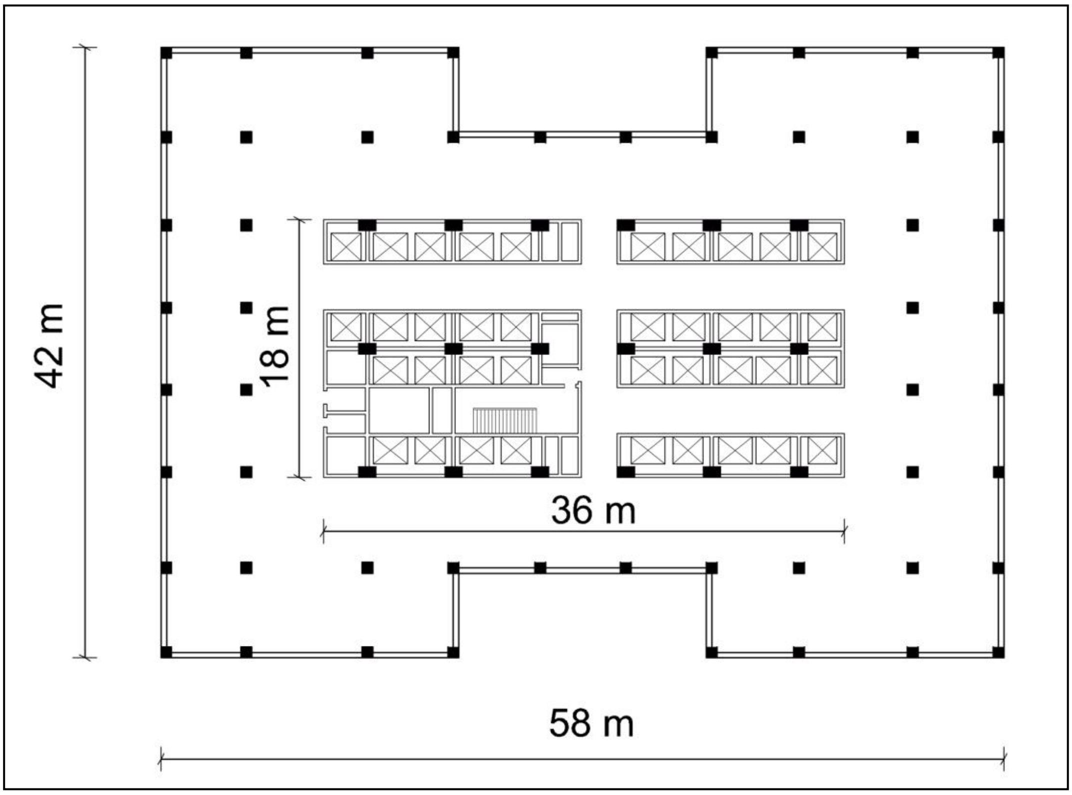


Figure 5.37 Typical Floor Plan

5.13 Central Plaza, Hong Kong, China, 1992

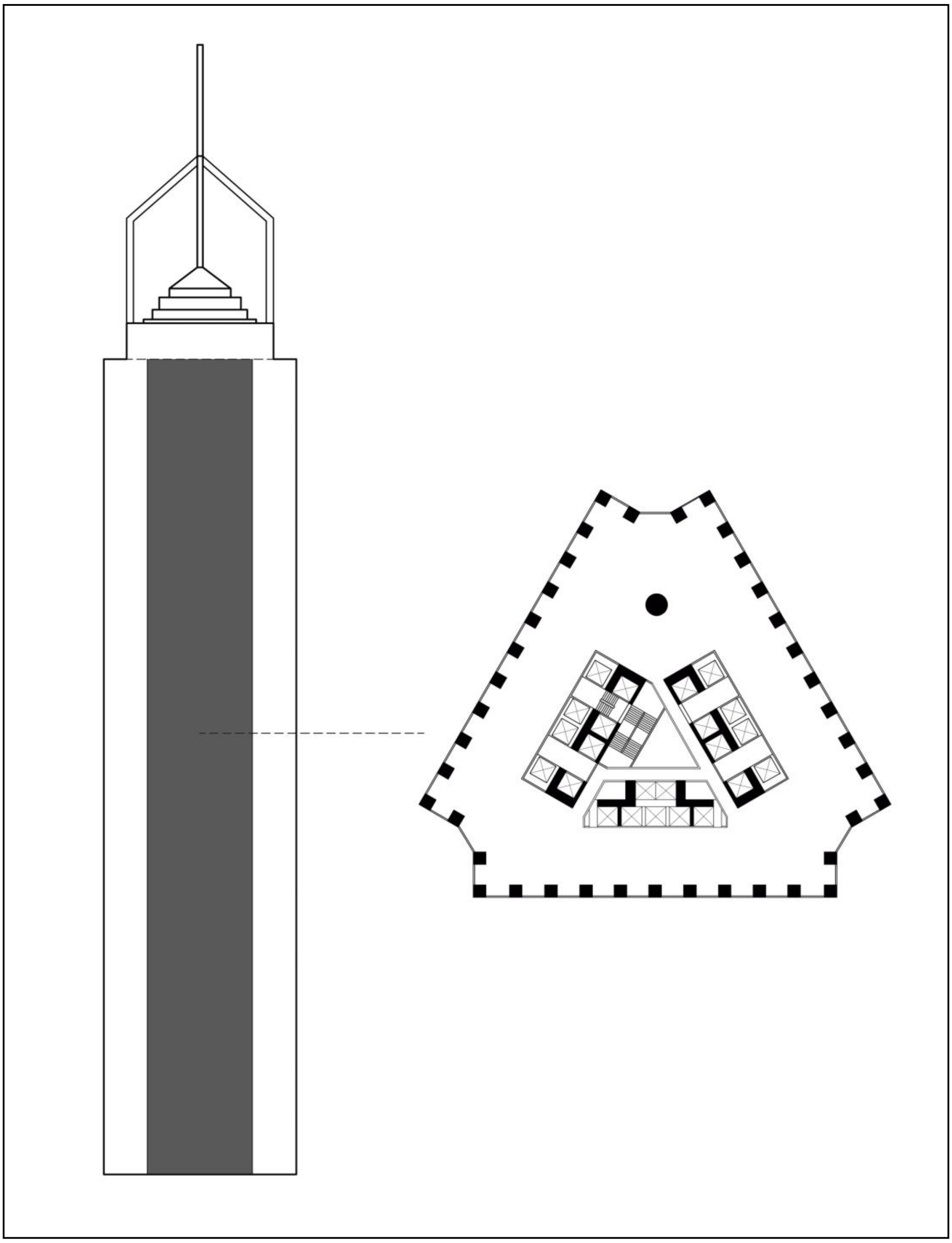


Figure 5.38 Section and floor plan of Central Plaza (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Hong Kong
HEIGHT	**:** 374 m
FLOORS	**:** 78
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 1992
ARCHITECT	**:** D.Lau & Ng Chun Man
STRUCTURAL MATERIAL	**:** Concrete
ELEVATORS	**:** 39
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA	**:** 443 m²
TYPICAL FLOOR AREA	**:** 2210 m²

Figure 5.39 General Information (source: CTBUH)

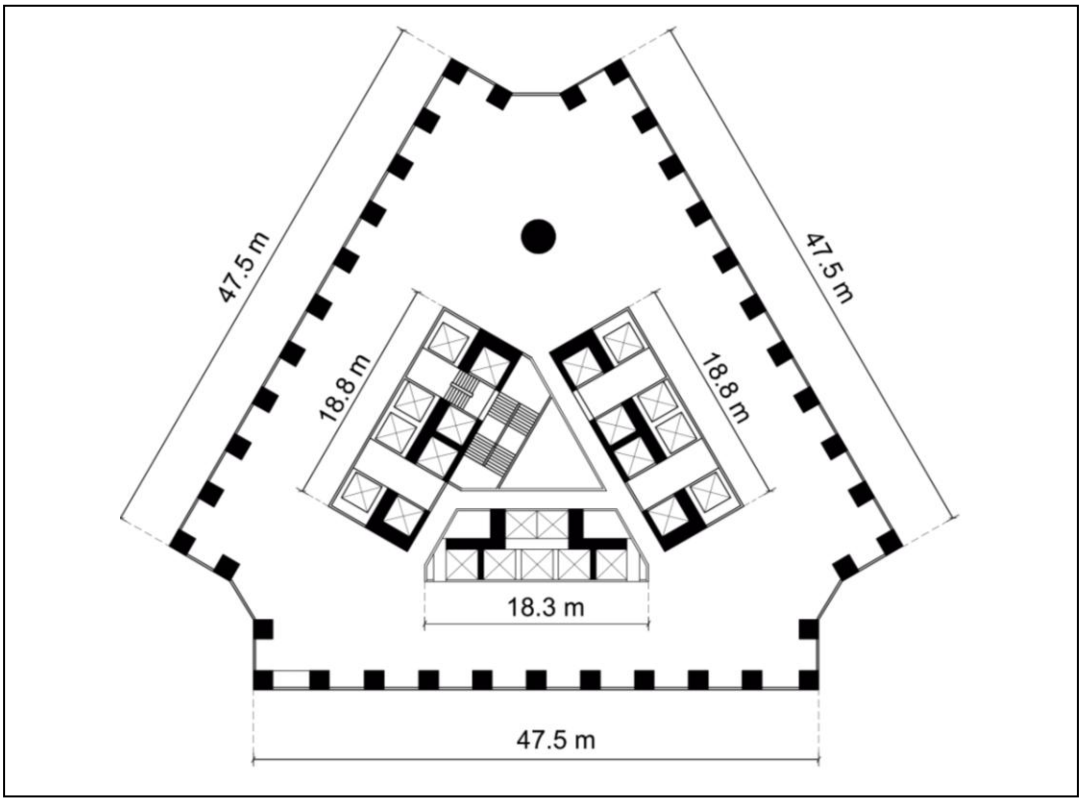


Figure 5.40 Typical Floor Plan

5.14 Bank of China Tower, Hong Kong, China, 1989

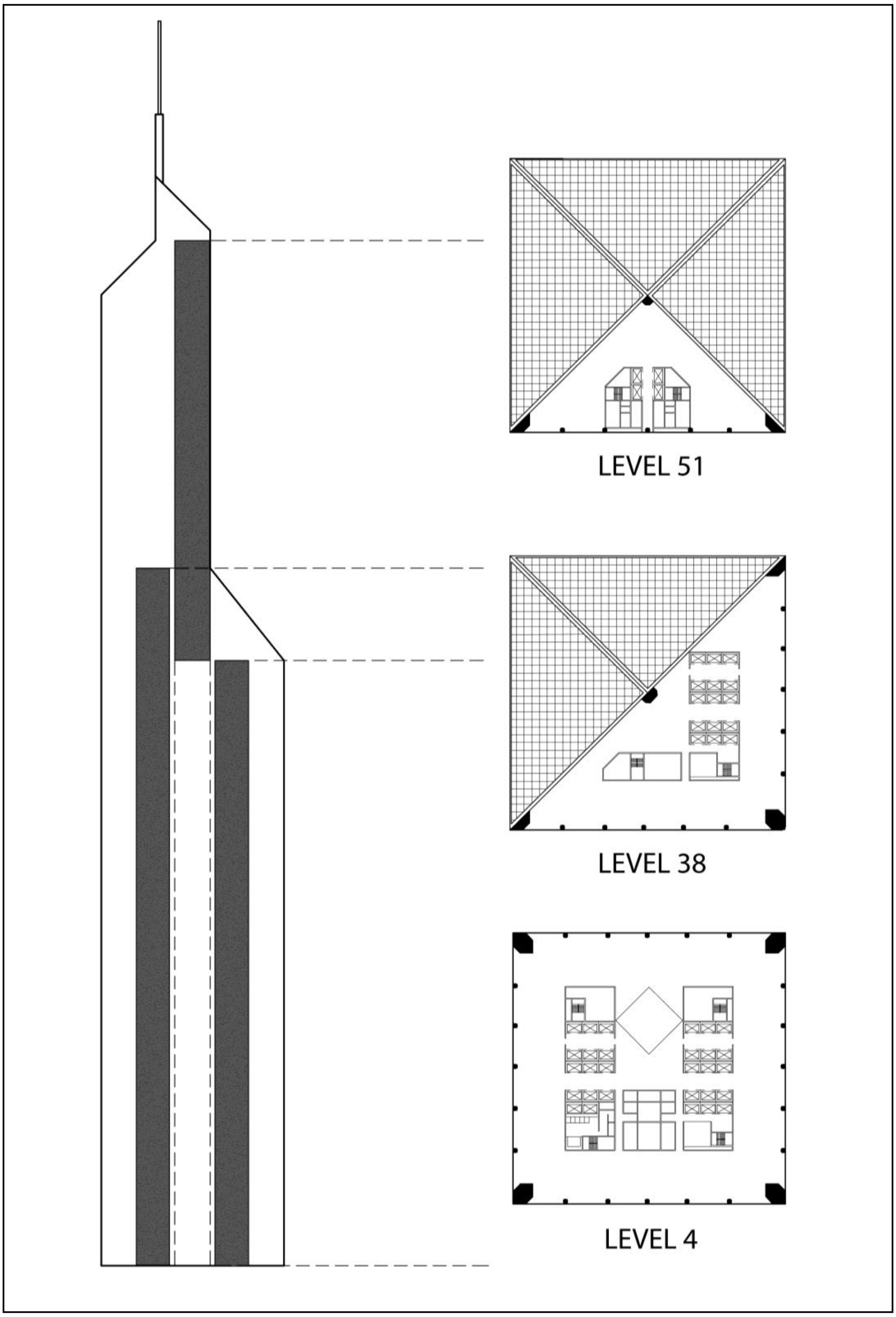
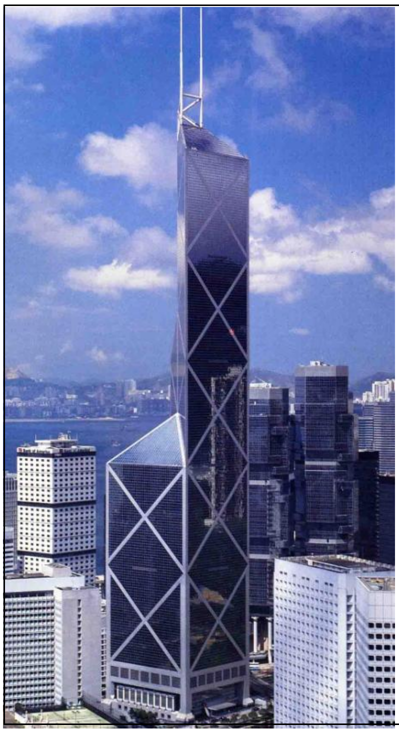


Figure 5.41 Section and floor plans of Bank of China Tower

(Drawing by Zeynep Keskin)



GENERAL INFORMATION	
LOCATION	**:** Hong Kong
HEIGHT	**:** 367 m
FLOORS	**:** 72
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 1990
ARCHITECT	**:** I.M.Pei & Partners
STRUCTURAL MATERIAL : Composite	
ELEVATORS	**:** 49
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 761 m^2	
TYPICAL FLOOR AREA : 2530 m^2	

Figure 5.42 General Information (source: CTBUH)

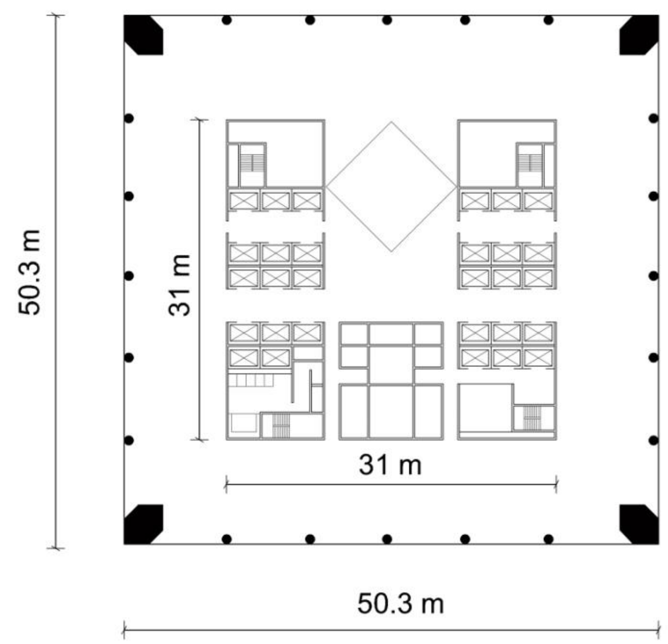


Figure 5.43 Typical Floor Plan

5.15 The Center, Hong Kong, China, 1998

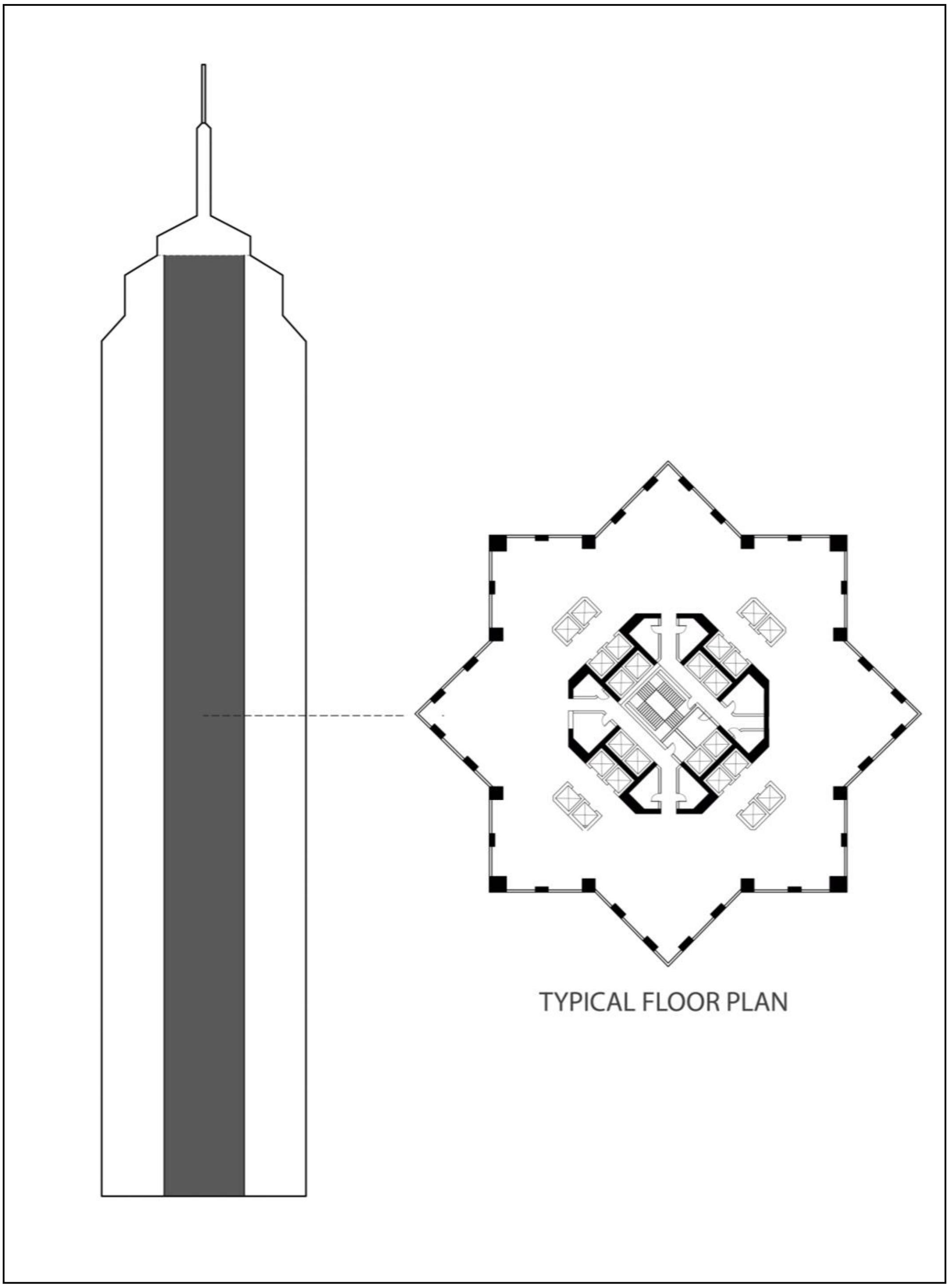


Figure 5.44 Section and floor plan of the Center (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Hong Kong
HEIGHT	**:** 346 m
FLOORS	**:** 73
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 1998
ARCHITECT	**:** D.Lau & Ng Chun Man
STRUCTURAL MATERIAL : Steel	
ELEVATORS	**:** 41
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 576 m²	
TYPICAL FLOOR AREA : 2100 m²	

Figure 5.45 General Information (source: CTBUH)

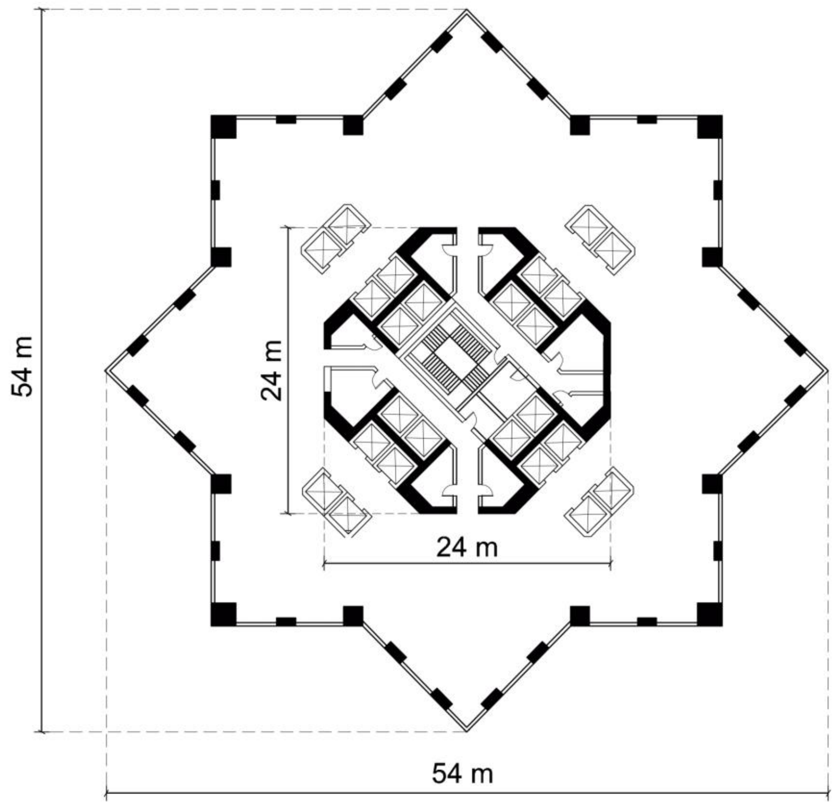


Figure 5.46 Typical Floor Plan

5.16 John Hancock Center, Chicago, USA, 1969

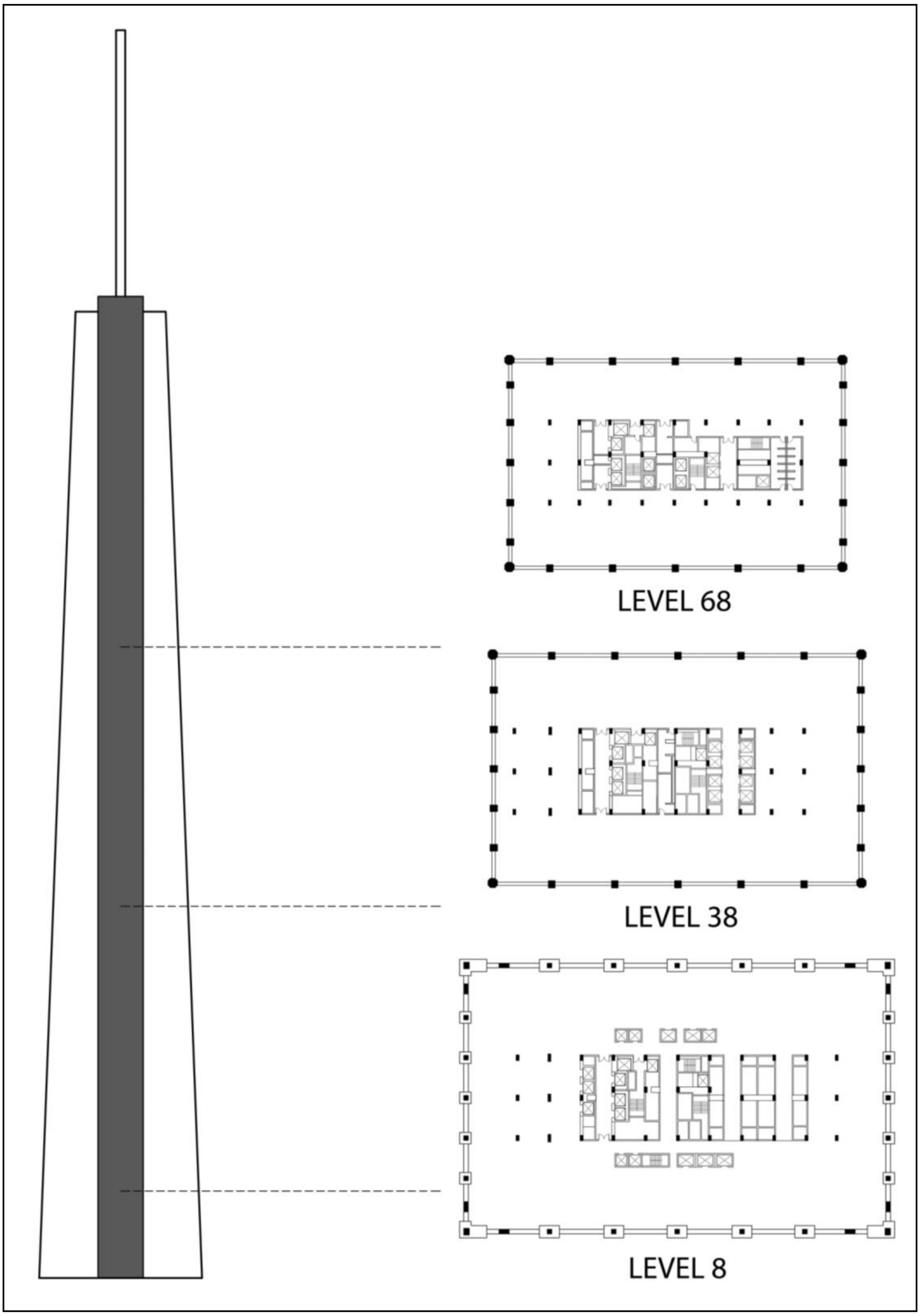


Figure 5.47 Section and floor plans of John Hancock Center (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Chicago
HEIGHT	**:** 344 m
FLOORS	**:** 100
FUNCTION	**:** Office/Residential
CONSTRUCTION DATE	**:** 1969
ARCHITECT	**:** SOM
STRUCTURAL MATERIAL :	Steel
ELEVATORS	**:** 50
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA :	883 m²
TYPICAL FLOOR AREA :	4000 m²

Figure 5.48 General Information (source: CTBUH)

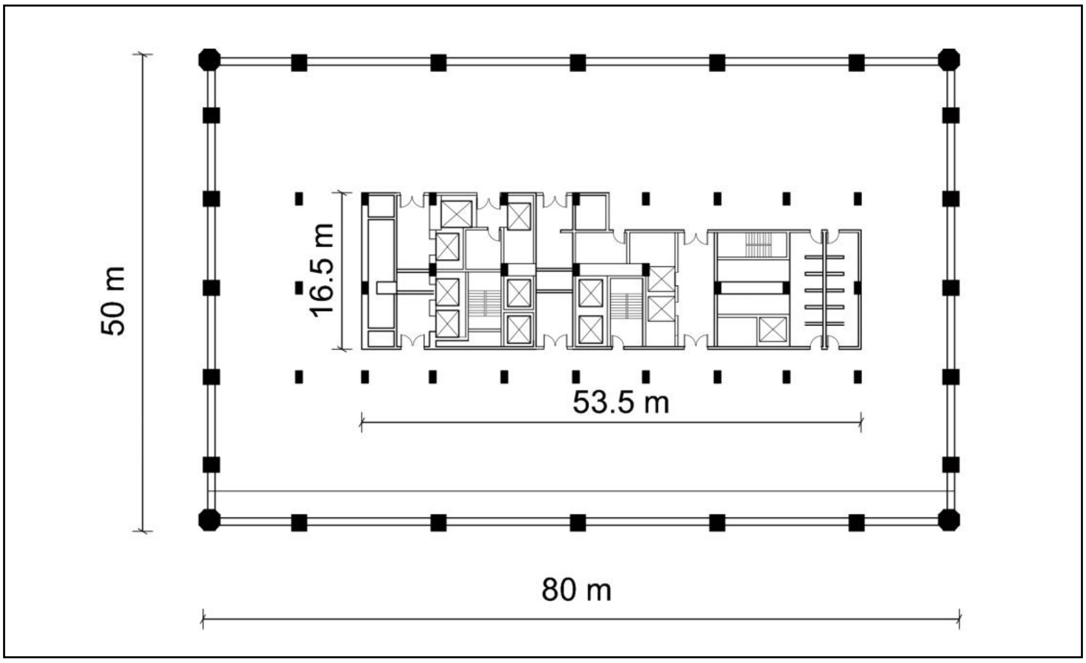


Figure 5.49 Typical Floor Plan

5.17 Chrysler Building, New York, USA, 1930

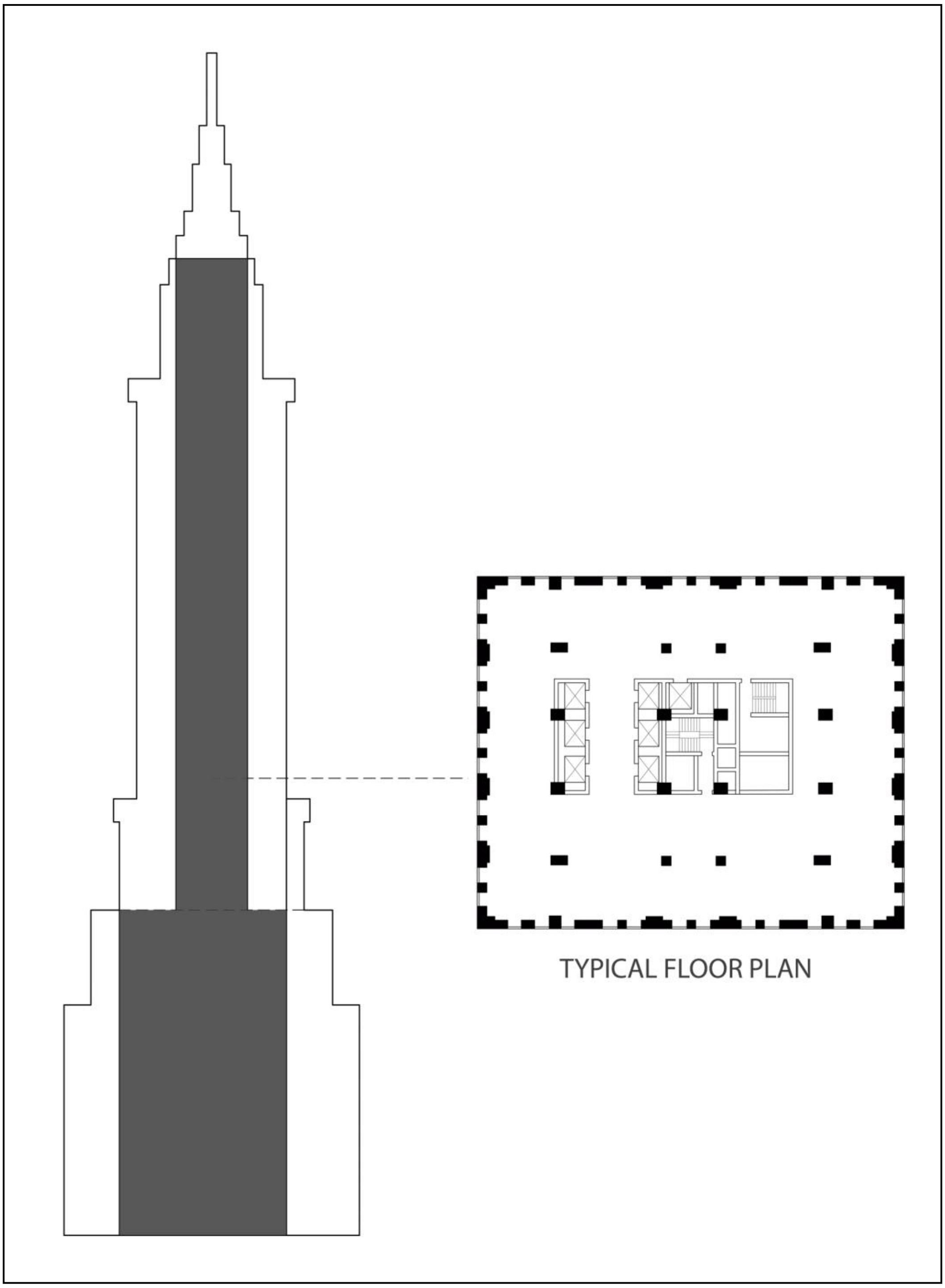


Figure 5.50 Section and floor plan of Chrysler Building (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** New York
HEIGHT	**:** 319 m
FLOORS	**:** 77
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 1930
ARCHITECT	**:** William Van Alen
STRUCTURAL MATERIAL : Steel	
ELEVATORS	**:** 32
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 158 m²	
TYPICAL FLOOR AREA : 861 m²	

Figure 5.51 General Information (source: CTBUH)

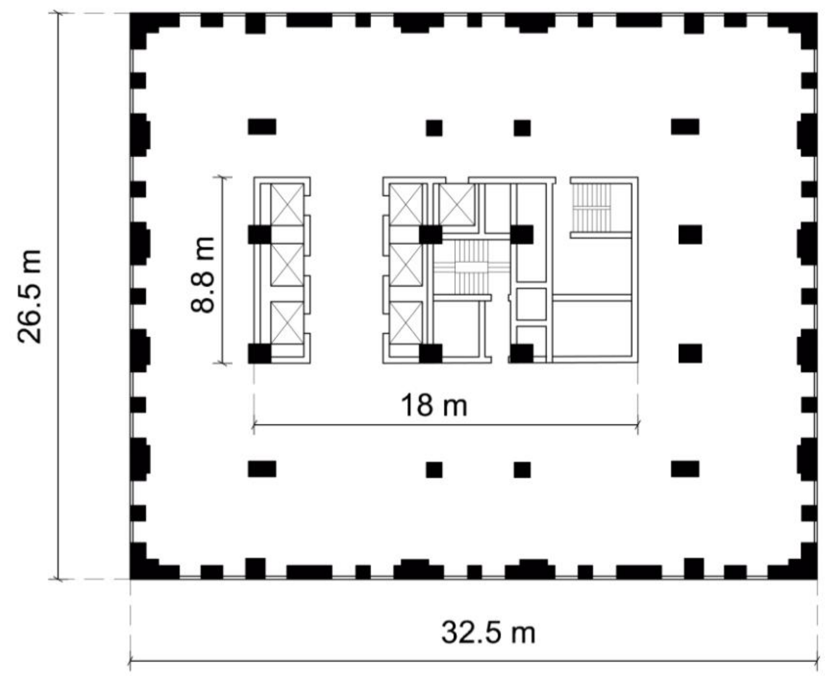


Figure 5.52 Typical Floor Plan

5.18 Aspire Tower, Doha, Qatar, 2007

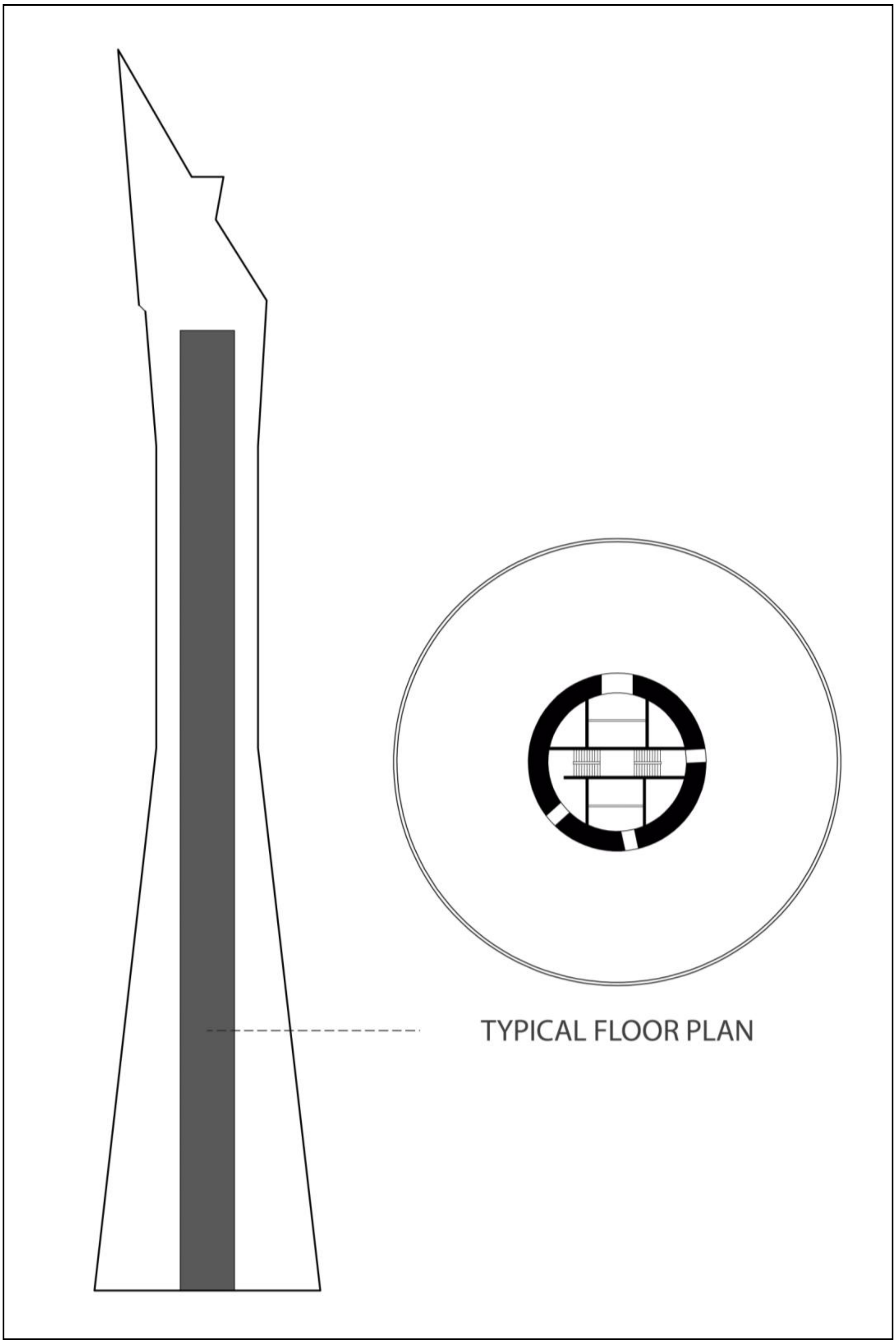


Figure 5.53 Section and floor plan of Aspire Tower (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Doha
HEIGHT	**:** 300 m
FLOORS	**:** 36
FUNCTION	**:** Office/Hotel
CONSTRUCTION DATE	**:** 2007
ARCHITECT	**:** Hadi Simaan
STRUCTURAL MATERIAL	**:** Composite
ELEVATORS	**:** 17
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA	**:** 176 m²
TYPICAL FLOOR AREA	**:** 1104 m²

Figure 5.54 General Information (source: CTBUH)

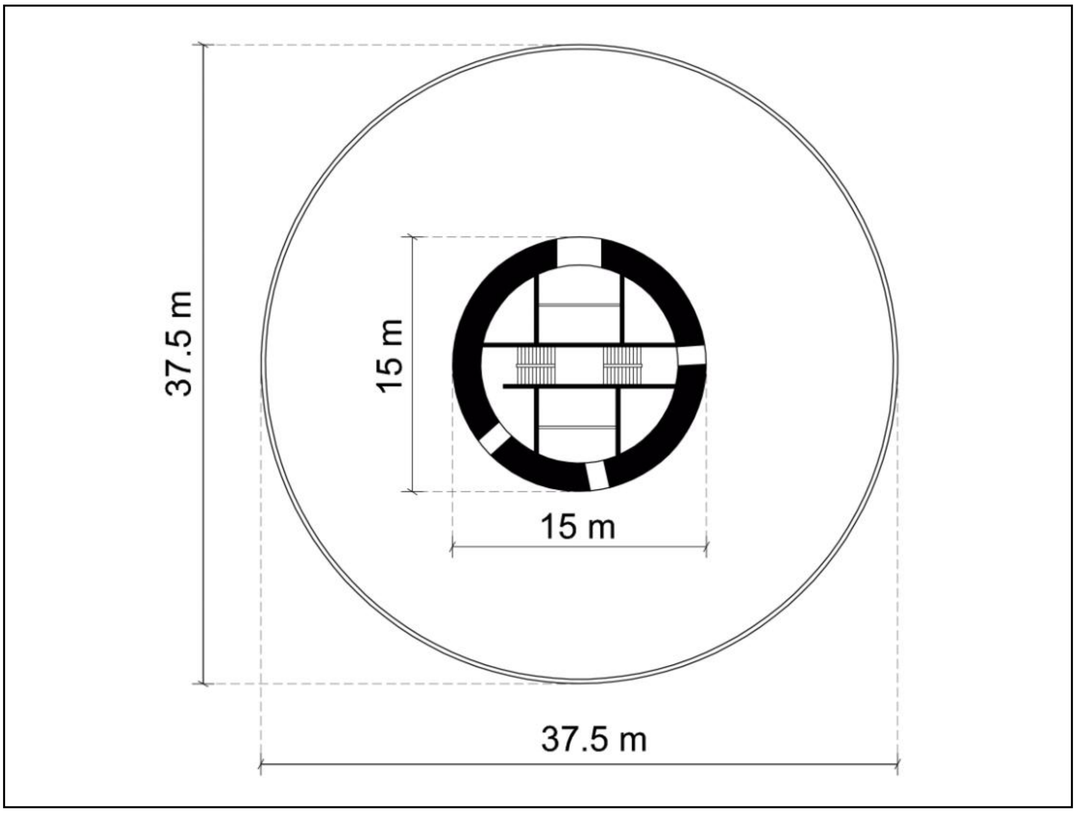


Figure 5.55 Typical Floor Plan

5.19 Plaza 66, Shanghai, China, 2001

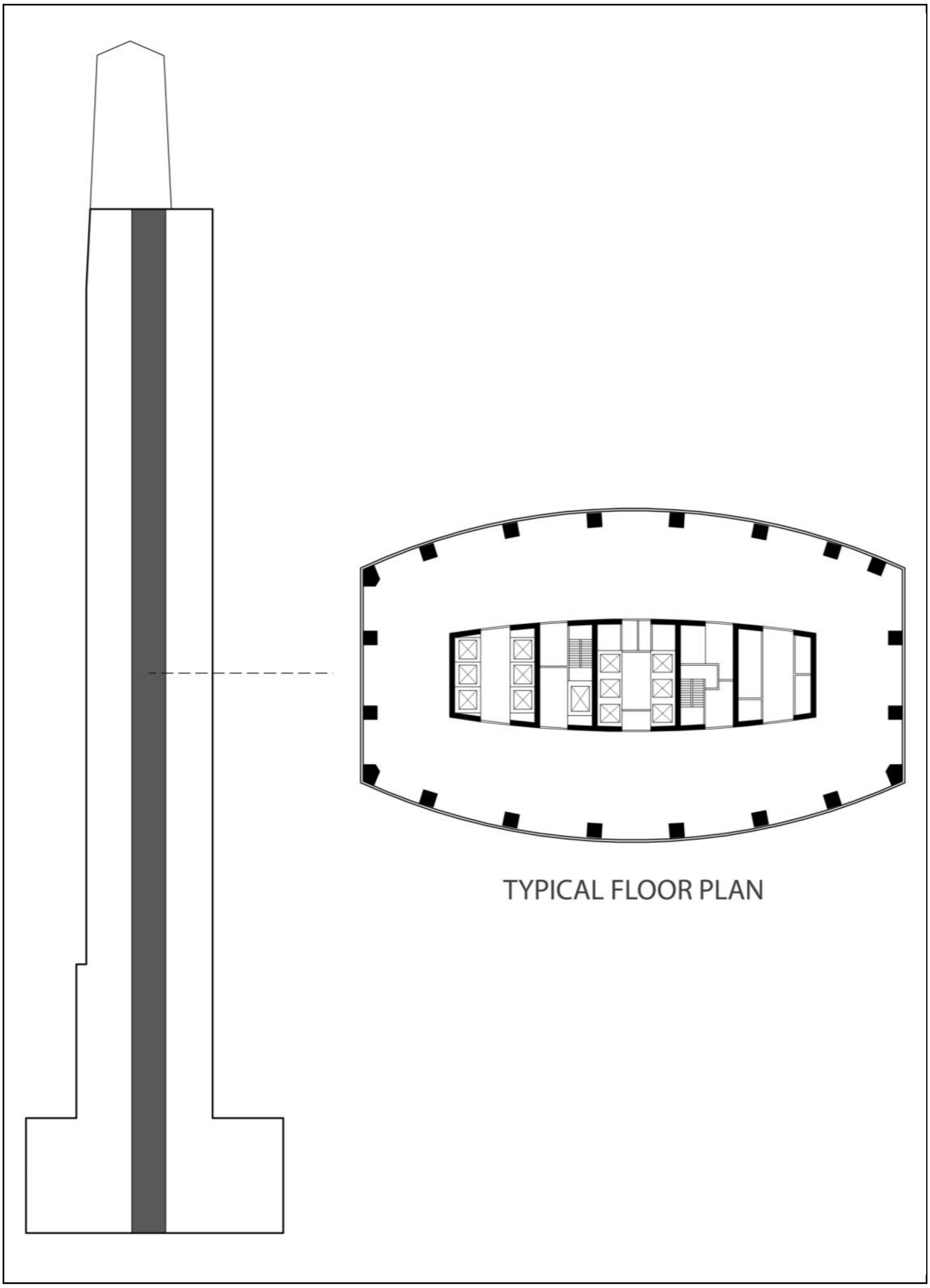


Figure 5.56 Section and floor plan of Plaza 66 (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Shanghai
HEIGHT	**:** 288 m
FLOORS	**:** 36
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 2001
ARCHITECT	**:** Kohn Pedersen Fox Assoc.PC
STRUCTURAL MATERIAL : Concrete	
ELEVATORS	**:** 19
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 400 m²	
TYPICAL FLOOR AREA : 1665 m²	

Figure 5.57 General Information (source: CTBUH)

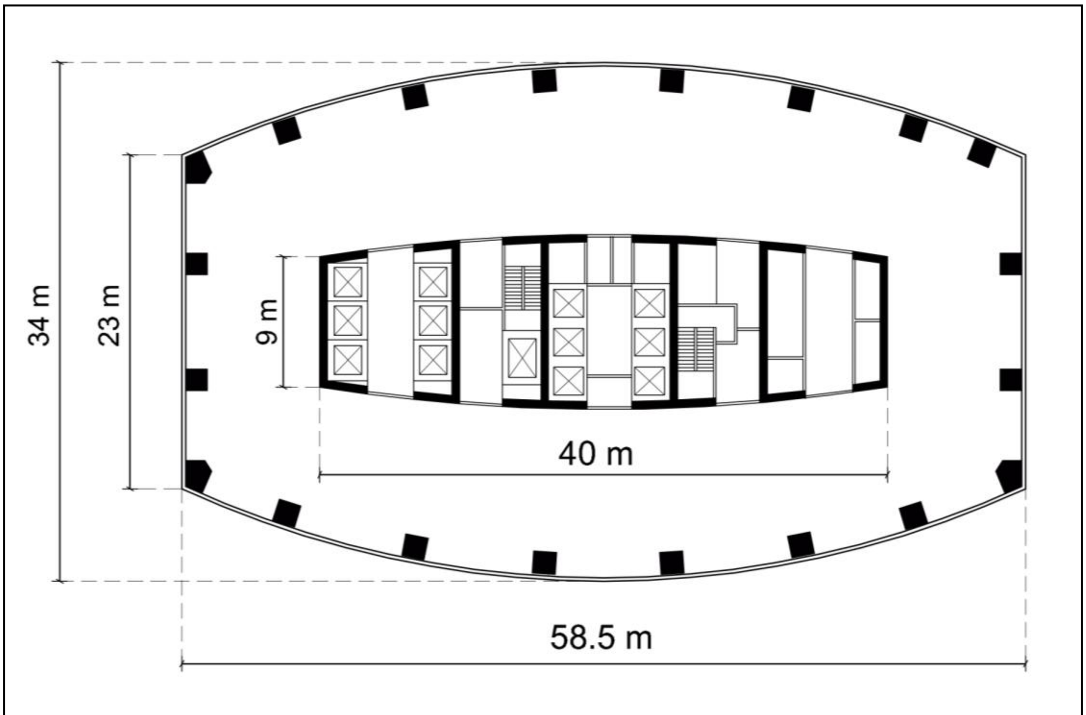


Figure 5.58 Typical Floor Plan

5.20 Cheung Kong Centre, Hong Kong, China, 1999

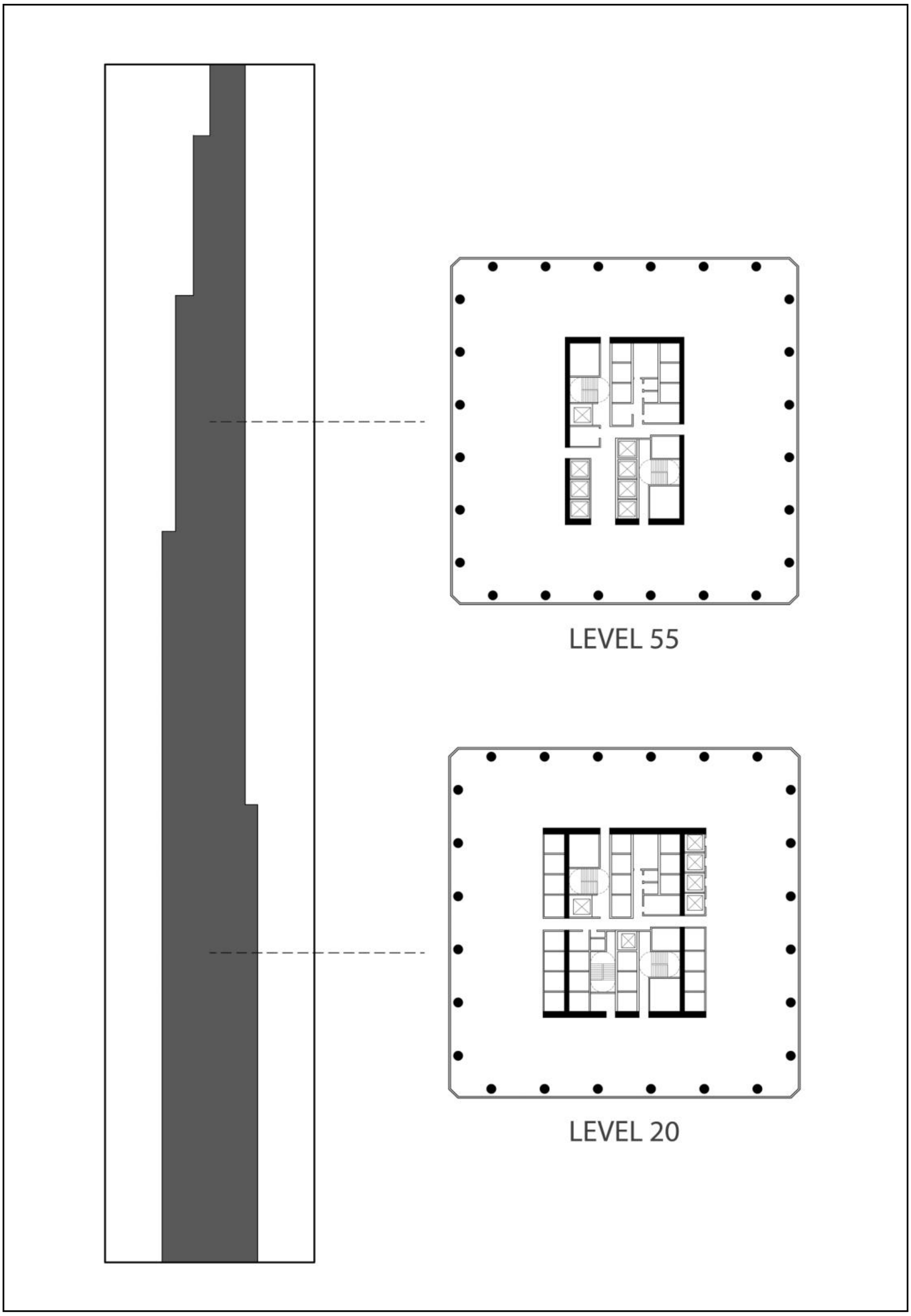


Figure 5.59 Section and floor plans of Cheung Kong Centre (Drawing by Zeynep Keskin)

GENERAL INFORMATION	
LOCATION	**:** Hong Kong
HEIGHT	**:** 283 m
FLOORS	**:** 63
FUNCTION	**:** Office
CONSTRUCTION DATE	**:** 1999
ARCHITECT	**:** Leo A.Daly&C.Pelli
STRUCTURAL MATERIAL : Steel	
ELEVATORS	**:** 30
SERVICE CORE	**:** Central Core
TYPICAL SERVICE CORE AREA : 594 m²	
TYPICAL FLOOR AREA : 2247 m²	

Figure 5.60 General Information (source: CTBUH)

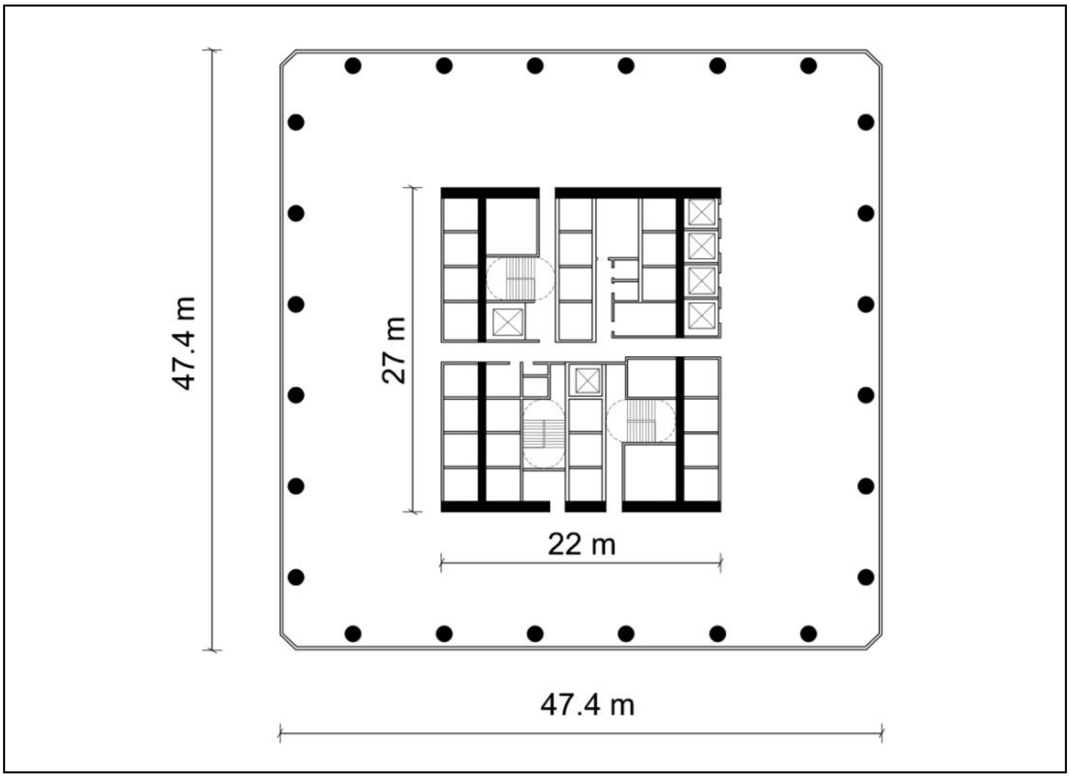


Figure 5.61 Typical Floor Plan

Table 5.1 Service core configuration for the tallest buildings in the world (100 tallest)

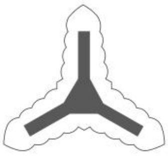
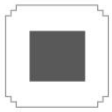
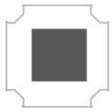
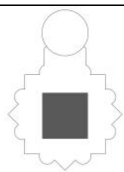
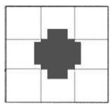
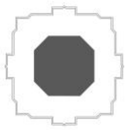
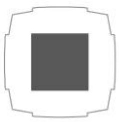
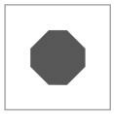
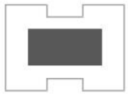
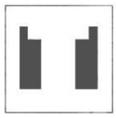
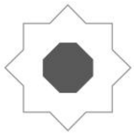
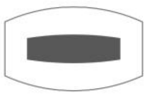
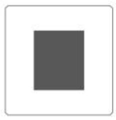
	Building Name	**Height (m)**	**Service Core**	**Configuration (ground floor)**	**Core/Floor Area (ground floor)**
1.	Burj Khalifa	828	Central Core		% 22
2.	Taipei 101	508	Central Core		% 25
3.	Shanghai World Financial Center	492	Central Core		% 28
4.	International Commerce Centre	484	Central Core		% 30
5.	Petronas Tower	452	Central Core		% 21
6.	Willis Tower	442	Central Core		% 19
7.	Trump International Hotel&Tower	423	Central Core		% 24
8.	Jin Mao Building	421	Central Core		% 26
9.	Two International Finance Centre	412	Central Core		% 24

Table 5.1 (continued)

10.	CITIC Plaza	390	Central Core		% 26
11.	Shun Hing Square	384	Central Core		% 30
12.	Empire State Building	381	Central Core		% 27
13.	Central Plaza	374	Central Core		% 20
14.	Bank of China Tower	367	Central Split Core		% 30
15.	The Center	346	Central Core		% 27
16.	John Hancock Center	344	Central Core		% 22
17.	Chrysler Building	319	Central Core		% 20
18.	Aspire Tower	300	Central Core		% 16
19.	Plaza 66	288	Central Core		% 24
20.	Cheung Kong Centre	283	Central Core		% 26

CHAPTER 6

DISCUSSION AND CONCLUSIONS

This study is focused on the investigation of the general characteristics of service core configuration and typologies; for this purpose, the speciality of service cores that play important role in planning considerations in architectural design of tall buildings was examined. This chapter presents the conclusion drawn from the research along with recommendations for future scope of work in the field of service core design for tall buildings.

6.1 Overall Review of the Research

In the frame of this study; service core design in tall buildings was searched with its different facets; how this building element influences on tall building design was examined; different design considerations for the service core were pointed out; the importance of service core for a tall building was explained; and finally, some proposals were pointed out for service core configuration together with their general characteristics in tall building design.

The appropriate configuration for the service core can only be determined by a multi-criteria, multi-disciplinary performance evaluation and developing a performance-based design methodology. The possibility of proposing different arrangements in service core layout is related to a variety of factors including the functional and structural requirements, safety and security performance as well as energy performance. The study reveals that a holistic approach to evaluation of parameters affecting service core design and investigation of those effects would help promote an efficient tall building design where all the important criteria would place on account in an appropriate and efficient manner. In order to do this evaluation, the study defined the factors which affect the design of service core and provided the method which can be used for understanding the effect of these factors on different service core configurations.

In this research, taking into consideration the studies in the literature, the classification for the service core configuration is proposed by the author as follows: (a) Central core configuration; (b) Peripheral core configuration; (c) Peripheral split core configuration; (d) External core configuration; (e) External split core configuration; and (f) Atrium core configuration, as summarized below:

- **The central core configuration;** in which the core is placed in the centre of the building is the most widely used configuration for tall buildings. This is mainly due to the important role of the core as a structural element contributing to the lateral load; and functional potential provided by the compactness of the configuration. Equally important, the need for openness in the exterior facade desired by designers for light and views, together with the implementation of the glazed curtain wall system, results in the service core elements to be located in the center. In addition, such a configuration provides advantages in terms of safety concerns, pushing all major spaces to the perimeter and allowing easy access for fire rescue. The central core configuration also can be divided into two or more elements to allow for a variation in tenant sizes and accommodations depending upon individual circumstances.

- **The peripheral core configuration;** in which the core is placed on the periphery of the building is generally implemented by designers taking into consideration the size of the floor plate and site conditions as well as environmental performance criteria such as energy, daylight or natural ventilation. This configuration is considerably more desirable for the buildings with smaller floor plates where the central configuration of service core is considered to be challenging due to the insufficiency of floor space for tenancy options or those where poor views or party walls present a problem. In terms of environmental performance, the peripheral service core placed on the hotter side of the building acts as a solar/thermal buffer while also having a shading effect on the occupied spaces, thus reducing energy requirements for cooling. Also in this case, positioned peripherally, the service core allows for natural ventilation, thereby diminishing the total volume to be mechanically conditioned. Additional advantages include access to daylight into the service areas, making the building safer in case of power failure, and eliminating the need for mechanical pressurization ducts for fire-protection. This configuration also provides the advantage of homogeneous workplaces, which is usually organized into one space, but demonstrates poor efficiency in terms of space use due to the extended circulation routes. On the other hand, the effective implementation of this configuration on large floor plates is challenging since the permissible distance from the furthest corner of the space to the fire escape is a limitation.

- **The peripheral split core configuration;** is characterized by the division of the peripheral core into two or more elements in order to accommodate special design considerations for large or long-narrow floor plates where the single service core becomes insufficient to serve the entire floor plate. Such an arrangement allows for easy access by reducing the corridor length although the number of service increases and the service system becomes much more complex compared to the single core where the services are concentrated in the floor plate.

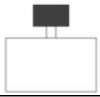
- **The external core configuration;** consists of an independent core system isolated by constructing the core as a separate mass element either attached directly to the building or connected by sky bridges. Architecturally, the exterior core configuration differs from other core configurations in that the core is given conspicuous architectural treatment to be identified outside of the building. The efficiency of this configuration is mainly derived from the shading effect on the building, natural lighting, and natural ventilation or from the idea that the solid structure of the core act as a thermal buffer and delay the heat gain of solar radiation. However, such a configuration has several drawbacks which inherently limits the functionality and create problems in the organization of internal space and traffic as well as in accessibility during emergencies as in the case of the peripheral core configuration.

- **The external split core configuration;** is characterized by the division of the external core into two or more elements since the single core is not sufficient to serve the entire floor plate in the case of large or long-narrow floor plates, suffering similar limitations to those outlined for the peripheral core configuration.

- **The atrium core configuration;** attempts to combine the benefits of external and peripheral core configurations such as natural ventilation and lighting to the case of central core configuration. It can be considered as a modified form of central core configuration. The incorporation of an atrium into a tall building can save energy by provision of daylight into the occupied spaces, forming a buffer zone between indoor and outdoor environment and providing natural ventilation with the help of the stack effect. However, it is important to note that the fire control is an important aspect of the atrium core design since the atrium could allow fire to spread to the upper floors more quickly by creating the chimney effect. The atrium core configuration can be divided into two or more elements, which is considerably more desirable than the single atrium core configuration in the case of large or long-narrow floor plates. In such buildings there is a possibility of visually interconnecting floors through the use of atrium and the potential to increase the number of service in the floor plate and allow for easy access.

From this conceptual basis, it is important to note and acknowledge the common understanding of major design theories that the service core design is a logical process that responds to some requirements including (i) functional and efficiency performance, (ii) safety and security performance, (iii) structural performance, and (iv) energy performance. These guidelines are not intended to be all-inclusive with respect to the selection of appropriate service core configuration for tall buildings since each building and site are unique, but rather to be an initial approach limited to the application of certain concepts the author believes to be critical in the design of service core for tall buildings (Table 6.1).

Table 6.1 A detailed representation of the service core configuration proposal

		Central Core	Peripheral Core	Peripheral Split Core	External Core	External Split Core	Atrium Core
CORE CONFIGURATION							
							
FUNCTIONAL AND EFFICIENCY PERFORMANCE	Flexibility of typical tenant areas	-	+	+	+	+	-
	Provision of homogeneous tenant space	-	+	+	+	+	-
	Optimal exploitation of the building's perimeter area	+	-	-	-	-	+
	Daylight, view for building perimeter	+	-	-	-	-	+
	Provision of a panoramic view from the core	-	+	+	+	+	-
	Clarity of circulation	+	-	+	-	+	+
	Ease of distribution of services	+	-	+	-	+	+
	Compactness of the core	+	+	-	+	-	+
	Distance of travel from core, typical	+	-	+	-	+	+
SAFETY AND SECURITY	Ease of access in the event of fire	+	-	+	-	+	+
	Safety of the building in the event of total power failure	-	+	+	+	+	-
	Provision of fire control for the core	+	+	+	+	+	-

STRUCTURAL	Structural core to resist lateral forces and avoid torsion	+	-	-	-	-	+
	Need for an additional structural system for core	-	-	-	+	+	-
ENERGY PERFORMANCE	Daylight, natural ventilation for core spaces	-	+	+	+	+	-
	The role of the core as a thermal buffer	-	+	+	+	+	-
	Shading effect of the core on the occupied spaces	-	-	-	+	+	-
	Increased envelope surface over volume ratio	-	-	-	+	+	-

As illustrated in Table 6.1, performance criteria for each configuration differ depending on many reasons including the size of the lot, building structure, function, neighboring structures, site and etc. For a number of categories, performance levels interact, but may also conflict with each other, requiring a problem-solving approach in order to maintain an optimal level of organizational performance. For instance, central core configuration provides structural advantages and efficient space planning for the tenancy, however does not provide natural ventilation and sunlight to the core spaces unless an atrium is designed for that purpose. Conversely, peripheral and external core configurations provide several advantages regarding environmental performance of the building such as shading effect of the service core on the building, natural lighting, and natural ventilation or the idea that the solid structure of the core act as a thermal buffer and delay the heat gain of solar radiation. On the other hand, such configurations have several drawbacks which inherently limit the functionality and create problems in the organization of internal space and traffic as well as in accessibility during emergencies.

6.1.1 Evolution of Service Core Configuration for the Tallest Buildings in the World

The central core configuration is the most widely used configuration for the tallest buildings in the world mainly due to the important role of the core as a structural element contributing to the lateral load; and functional potential provided by the compactness of the configuration. In the case of very tall buildings which pose serious challenges from both structural design and construction points of view, it becomes imperative that the service core is integrated with the structural system. As a consequence of these restrictions, service core is generally placed in the centre for very tall buildings.

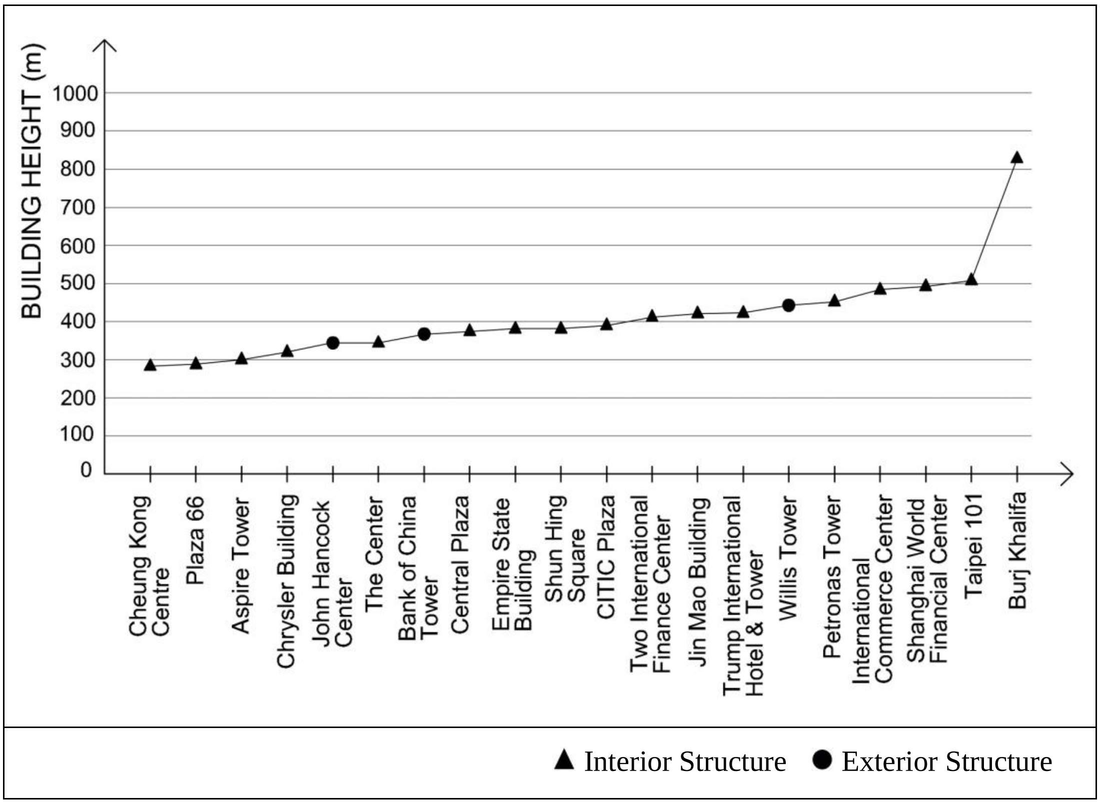


Figure 6.1 Comparative heights and structural systems of several of the world's tallest buildings

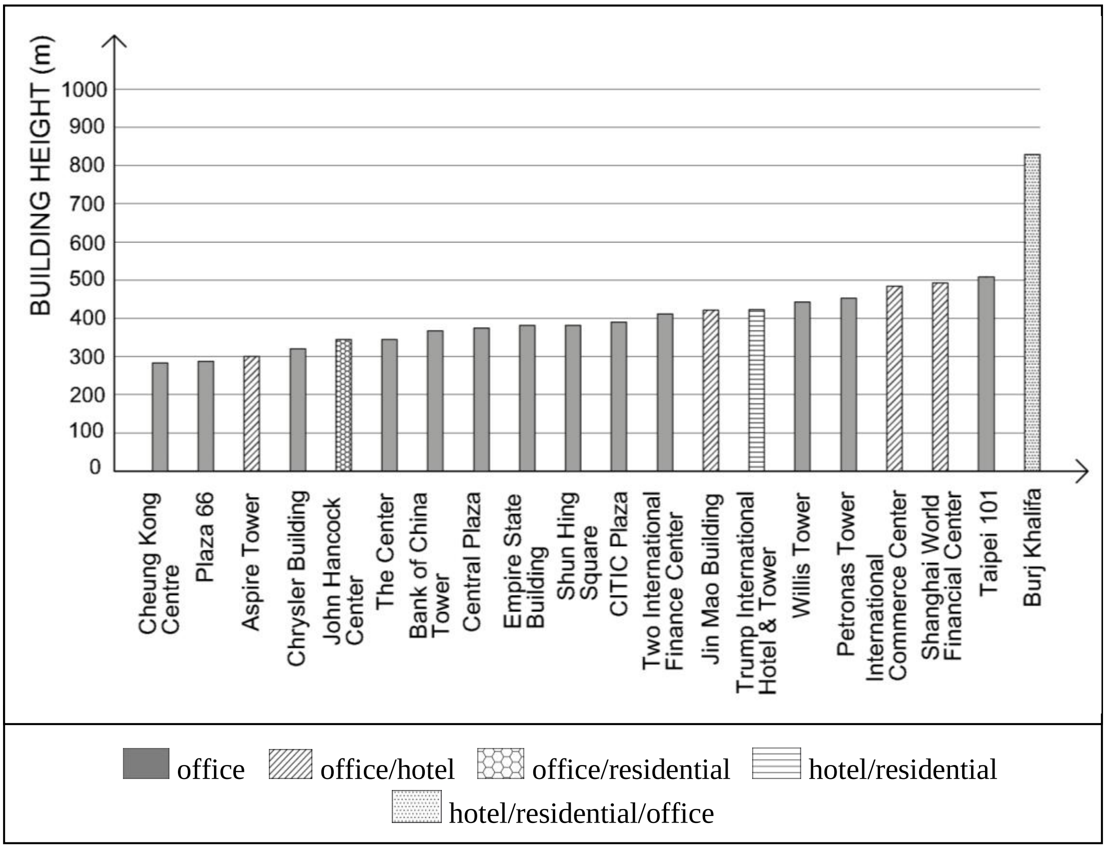


Figure 6.2 Distribution of function for each sample building

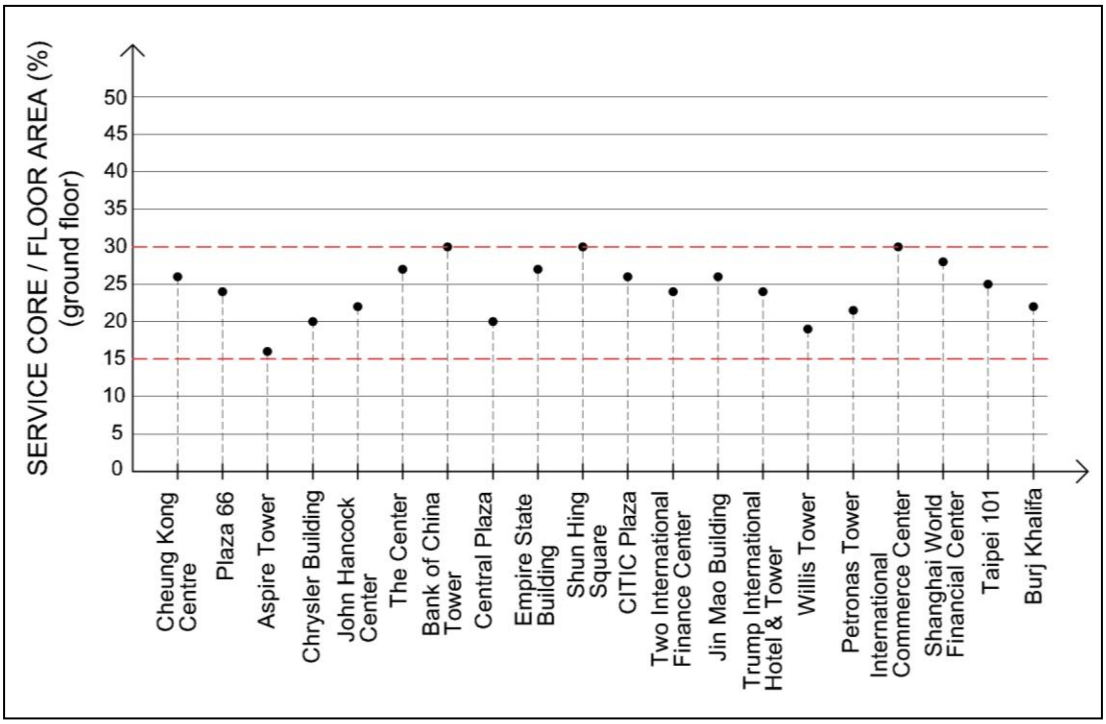


Figure 6.3 Distribution of service core area for each sample building (ground floor)

6.1.2 Evolution of Service Core Configuration for Different Climatic Conditions

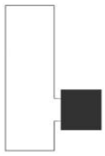
In recent years, there has been a growing number of tall building design that aim to use less resources and reduce the energy consumption since the amount of energy required by these buildings became a major issue after the energy crisis in 1970s. The increased sensitivity to the environment and the limited natural resources influence the design of the service core, and encourage architects to find effective ways to integrate the environmental concerns into the design process. As a result of those remarkable changes of attitude in planning and design issues, service core design has changed dramatically and new configurations have been adopted which play a great role in achieving sustainability at the core level. As such, the conventional approach to service core design in the past was to have the service core in the central position mostly, but today, much more complicated configurations for the service core could be utilized depending on different climatic conditions (Table 6.3). Consequently, possible configurations for the service core and their effects in different climatic conditions can be summarized as follows:

- The external and peripheral service core configurations are considered to have significant roles in the energy performance of a tall building since they create the basis for considerable savings on the energy consumption. This is achieved by meeting the two objectives; a) since the service core becomes a transitional space between the inside and the outside of the building as in the case of external and peripheral configurations, it can mediate the differential temperature and serves as a solar buffer, thereby enabling a passive low-energy bioclimatically responsive configuration; b) utilization of natural ventilation and natural lighting as primary means for creating thermal comfort.

- The major advantages of the external service core mainly originate from the shading effect of the service core on the building, or from the idea that the solid structures of the core act as a thermal buffer and delay the heat gain of solar radiation.

- The external split core and peripheral split core configurations provide many advantages in terms of thermal performance of the building. These configurations might be adjusted in accordance to the sun-path route and can contribute to the energy reduction. In hot climates, such configurations are preferable with the service cores on the east and west side of the building, acting as thermal-buffer zones to the internal spaces. In temperate and cold climates, the service core could be designed to protect from the cold winter winds by locating the service core on the colder sides of the building such as north-east and north-west.

Table 6.2 Service core configuration for different climatic conditions

Building Name	**City**	**Height (m)**	**Year**	**Function**	**Service Core**	**Configuration**
Menara Ta1	Kuala Lumpur	151	1996	Office	Peripheral Core	
One Bush Plaza	San Francisco	94	1959	Office	External Core	
Inland Steel Building	Chicago	101	1958	Office	External Core	
Mitsui Marine & Fire Insurance	Tokyo	104	1984	Office	External Core	
IBM Headquarters Building	Tokyo	105	1989	Office	External Split Core	

As a consequence, the fact that the design of very tall buildings is mainly governed by the structural requirements for lateral load resistance results in the implementation of central service core which serves at the same time structural function. However, the increased sensitivity to the environment and recent trends related to sustainability issues encourage architects to design the service core with a variety of possible configurations in order to reduce energy consumption of the building. That is, before the energy crisis of the early 1970's, the energy consumption for a tall building was a minor concern in relation to other design considerations because of the structural and technological priorities and relatively inexpensive energy supply, it was not considered necessary for service core design to respond to local climate characteristics and solar effect. But today, there are several service core typologies which can be used to improve the energy performance of such buildings by integrating climatic conditions into the design process.

6.2 Contributions of Research

Service core design is multidisciplinary and it has generated applied research that lacked a coherent theoretical framework until recently. The solution that is most appropriate for a particular case depends on the assessment of basic design factors. Architects and engineers should be aware of the necessity of establishing guidelines for the design of service core for tall buildings. In this context, this study gives recommendations in terms of general guidelines for the implementation of service core configuration to be included as part of the design of the tall buildings. It views service core design typologically, identifying different characteristics in tall building design; and interprets these as the basis for the generation of service core classification. Based on previous research and practical experiences, this study provides a systematic review and discussion of the practical issues involved in designing and implementing service core configuration and typologies. The reviews and discussions are intended to be concise, simple, and systematic, and alternative options are discussed in a succinct manner, so that they can be readily used by interested designers and researchers.

6.3 Recommendations for Future Research

Service core configuration and typologies have certainly become a recognized area of expertise essential to the design process of tall buildings. In this research, some factors about tall building design such as planning modulation, lease span, floor height as well as their relationship with the service core design are not discussed in much detail. They are, however, herewith observed in the framework of tall building design in order to emphasize that the service is one of those factors that is important for the design of tall buildings. However, the study can be elaborated in a further analytical survey related to those factors including building efficiency evaluations with specified materials and techniques, which goes beyond the thesis.

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