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Historical evolution of the service core

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Dario Trabucco is an architect and contract professor of building technology at the IUAV University of Venice, Italy. He recently concluded a PhD in building technology with a thesis on the design of the service core of tall buildings. His research activity is now focussed on the relationship between this element and the running consumption / embodied energy of a tall building.

"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 service core is the distinctive feature of a tall building: it provides the skyscraper with structural solidity, room for elevators, toilets, and other amenities, and constitutes the main network for utility services, power and data. Though many of these elements were present even in the very first examples of this building typology, the actual service core is the result of an evolutionary design process that has taken more than one hundred years and is still evolving. The present paper examines the designs from the early skyscrapers of Chicago and Manhattan, through the zoning restrictions and the technological innovations of the post-World War II period, to the present modern control procedures of the elevators. The role of the service core has always influenced many aspects of the whole design of tall buildings concerning the structural system, the access/egress strategies and sometimes even their shape. The future trends for the evolution of the service core are mentioned including the innovative design strategies adopted in some recent skyscrapers.

The Early Years of the Tall Building

The first buildings that surpassed the 6-story threshold quickly started to define new standards of spatial design that partly changed the architectural traditions determined in the previous centuries: not the magnificent staircase of the renaissance palazzo but the elevator core became the focal point of the building (Hill, 1893).

In order to understand the evolution of the service core, it is necessary to retrace the origins of the tall building typology, stemming from two American cities: New York and Chicago. Even though the Home Insurance Building is often considered the first skyscraper, the origin of this building typology is still disputed by many (Condit 1960, Mujica 1930; Schuyler 1961, Weisman 1970). Despite this, it is commonly agreed that tall buildings required the presence of the following elements in order to be feasible; an author described the rise of skyscrapers in the moment it happened (Fryer, 1891): "*Today there is simply no limit to the height that a building can be safely erected. This result has been reached mainly through three inventions, all of which are distinctively American: 1) the modern elevator; 2) the flat-arch system for fire-proof floors; 3) the skeleton construction. The last enumerated one has only lately joined the combination in which the first two were so long inseparable*." As it can be seen in this statement, two technical reasons (the possibility of building tall and the possibility to make the high levels easily reachable) are jointed with a third , which is the consequence of safety concerns (fireproofing floors, in order to make the building safe). In fact, it should be noted the singular coincidence that many tall buildings rose on the same plots of previous buildings, completely burnt in disastrous fires (Weisman, 1970).

However, the key feature that made tall buildings possible was the elevator, since many masonry tall buildings rose before the acceptance of metal skeleton structures (one example is the Monadnock building in Chicago). The role of the elevator was so important that the first descriptions of such new typology refer to them as "*elevator-building*" or "*elevator-architecture*" (Unknown, 1895)

Despite the common basic ingredients, it must be emphasized how the initial evolution of the tall building typology led to the distinction of two completely different organizational schemes (a slender tower or the "*quarter blocks*"), linked to the historical and urban characteristics of the two cities, New York and Chicago, where they developed.

...adaptive reuse

"It's really challenging to convert an office building into a hotel. The Foshay project says something about adaptive reuse and the importance of saving a beautiful existing building."

Lucien Lagrange, principal of Lucien Lagrange Architects discussing the challenge of the Foshay project. From 'Monumentally Hip Hotel Conversion' ,Building Design and Construction, September 2009, pp 14-15

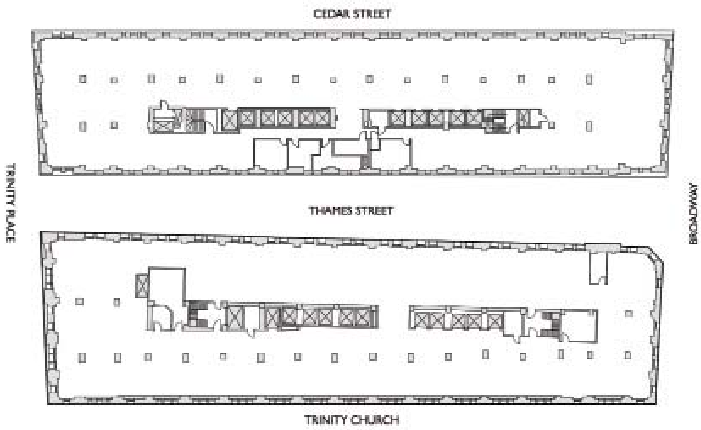

Figure 1. The Trinity and the US Realty Buildings have a long bank of elevators disposed on one side of the corridor

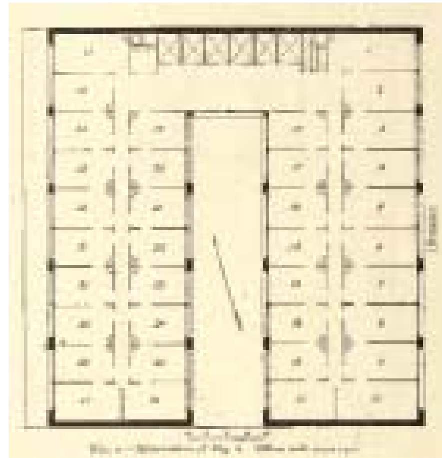

Figure 2. Proposed building for New York. The Architectural Record Vol. 2. April-June, 1893. n° 4.

The tale of two cities: New York and Chicago

New York: Since 1892, when the utilization of metal structures was approved by the building code of New York, the height of office buildings began to exceed 16 floors on a regular basis. The first tall buildings were laid out on long narrow lots, 20 to 30 meters wide in front, stretching for the full width of the Manhattan grid (60 to 70 meters) in depth. However, there are examples of smaller lots, corresponding to about half of a block. The shape of the lots was interpreted by architects in two different organizational schemes, based upon the internal traffic system.

The first type designed the buildings on almost square-shaped parcels with a system of 4 to 6 elevators commonly located in a central position, with offices opening directly into this central area of communication. The short central hall, about 2.5 meters wide, was flanked by elevators that took up an additional space of 2.5 meters on each side. A corridor allowed direct access to the offices located around the central unit. The typical core-to-wall distance had a maximum depth of 8 to 9 meters, which corresponded to the optimal distance beyond which natural light, coming from the windows, was too weak to allow workers to carry out their activities. At this time, electric and gas lamps still had very poor efficiency. The sum of widths, calibrated on this construction and functional "*optimum*", gave a total measure of about 25 meters, which corresponded to the average width of a lot. Such configuration recurred also in the depth of the building, with the most appealing offices behind the main street façade.

The second type varied remarkably in buildings that occupied the entire depth of a city block. In this case, the greatest depth determined the distribution corridor. On one side, elevators were organized in a long row, sometimes up to 12 to 14 cars in a row. Also in this case, the central disposition allowed an optimal exploitation of the building's perimeter area, guaranteeing sufficient natural illumination on the working side of the spaces (Osterhaus, 1993) (see Figure 1).

The central position of the vertical communication center was a representation of a norm, but not a rule. In a few designs, some conditions suggested a different organization of the vertical traffic system, such as the possibility for the building to be flanked by another neighboring structure along its entire height. In such a case, the vertical traffic system would have found itself again, considering both buildings, in the central position (see Figure 2).

The location of the other practical-use spaces necessary for the building (restrooms, electrical closets and vertical ducts) varied from case to case. They were usually placed in a peripheral position, so as to be easily ventilated, occupying the less lucrative zones of the building.

Chicago: At the same time, the architectural experience taking place in Chicago created completely different results. The grid on which the city was planned was formed of large, almost squared blocks about 100 x 100 meters wide. Such a condition, combined with the city's vicissitudes (amongst which the Great Fire of 1871), made large lots possible, often corresponding to an entire quarter of a block. Buildings of impressive dimensions could then be built, precisely called "*quarter blocks*" (see Figure 3).

Such buildings were about 50 x 50 meters in plan and their height was limited by regulations much more strict than those enforced in New York. During the first decades of the 1900's, building regulations fixed the maximum building height between 45 and 90 meters. These limits led to erecting massive structures, in some cases perfectly cubical, which had to exploit the building opportunities imposed. The construction of office spaces, as proof of the speculative value of skyscrapers, was determined in a precise way: "the ideal office *is 5,5 x 7,5 meters (18 x 25 feet in the original text, note of the author). The fenestration should be arranged so that it would be possible to subdivide the 5,5 meter long (18-foot long) office unit in two parts to provide two small offices, each with a window, and in the back of the two offices*

Figure 3. Railway Exchange Building, Chicago. A "quarter Block". The Architectural Record Vol 17, n° 5, May 1905

approximately 4,5 x 7,5 meters (15 x 18 feet), to have a small anteroom" (Gompert, 1930). The most efficient solution to create the largest number of "*ideal*" sized offices in the massive quarter blocks was to excavate an illumination well on the inside of the building volume, and organize the offices in two concentric rings. The more prestigious offices faced the main street, while the less attractive ones faced the internal illumination well (see Figure 4). However, such spatial distribution deprived the heart of the building of all distributive function. Therefore, the system of vertical transportation had to be located in an off-center position. The elevator banks were consequently aligned down a single row (see Figure 5). They were usually attached to a perimeter wall, rather than to one of the walls of the internal cavity, because of the possible development of an adjacent building on an interior lot line. When this adjacent building is built, it would have transformed offices on the interior lot line of the building's perimeter into blind spaces. Their location in the building plan caused some offices to be sited at a considerable distance from the elevators. In order to facilitate the inter-floor communication (more than evacuation) internal stairwells were often provided at the angles of the internal corridors. In this way the inter-floor traffic was divided between stairs and elevators.

The issue of fire egress was treated through the use of external stairs in both New York and Chicago. Despite the fact that exterior metal stairs can still be seen in many ancient tall

Figure 4. Light well of the Railway Exchange Building in Chicago. The internal walls were clad in white tiles in order to reflect the light into the offices located in the lower floors

buildings, it was acknowledged "*the exterior fire escape is by common consent considered useless as a means of egress from even moderately tall buildings*" (North, 1930) (see Figure 6). For this reason the internal staircase was often enclosed in a masonry well, which provided more adequate protection. In the Woolworth Building, we notice an early example of what can be considered a modern fire exit, though it includes some "*mistakes*" (such as the opening direction of the door that opens into the stairwell, stopping the people's flow). During this first period of the era of skyscrapers, the service core had little structural relevance, especially in Chicago where the massive shape of the "*quarter blocks*" required less structural resistance to withstand the horizontal forces. Also, the more slender towers of New York had a structural scheme that did not require a rigid core because the rigid frame steel skeleton supported both the vertical and the horizontal loads.

The Influence of the Zoning Law

In 1916, after long discussions (Blackwell, 1913), New York approved the Zoning Law, the first urban tool to control Manhattan's chaotic expansion. This regulation wasn't motivated, or at least not entirely, by philanthropic and environmental intents. The Equitable Building is often stated as the cause of the Zoning regulation, which prevented new massive skyscrapers from blocking sunlight and clean air to the streets (Robins, 1996). Although this was

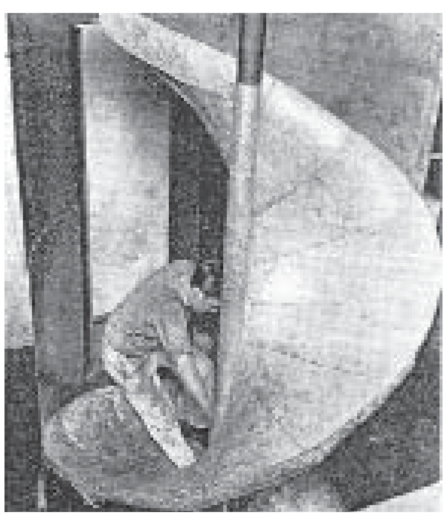

Figure 6. The Spiral Slide Escape, a patented means of egress in case of fire. The Architectural Record, February 1931

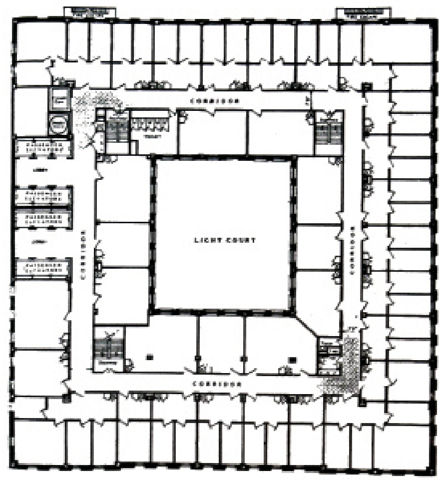

Figure 5. Straus Building, Chicago. Typical distribution of a "quarter block" building.

indeed the most noticeable outcome, the Zoning Law was actually created in order to "*stabilize and conserve property values, to relieve the rapidly increasing congestion in the streets and the transit lines, to provide greater safety in buildings and in the streets, and in general to make the city more beautiful, convenient, and agreeable*" (Ford, 1916).

The motives behind such regulation appear predominantly economic/speculative in character. They can be found in the action of a lobbying group with headquarters located a few kilometers north of the Equitable Building. The properties of the affiliates of the 5th Avenue Area Merchants Association were threatened by the "*hordes of factory employees*" (Weiss, 1992), who's companies recently moved Uptown after an increase of property values in Lower Manhattan. Moreover, the same real estate businessmen, first reluctant to placing limits on building dimensions, quickly changed their minds when they saw that the value of a property was frequently jeopardized by a new taller or more fashionable skyscraper, built in the immediate neighborhood. Such self preservation, joining with the understanding that the proximity and height of buildings could cause a series of dangerous fires, overthrew the last and strongest opposition to Manhattan's characteristic laissez-faire attitude (Willis, 1986) (see Figure 7). With the application of the Zoning Law, which allowed unlimited heights on only 25% of the lot, the shape of buildings was modified by law, and with it the service core requirements. As Corbett accurately

Figure 7. Clustered skyscrapers in downtown Manhattan

Figure 8. The Palmolive building in Chicago. A building that follows the fashion of the setback style in a city where no zoning codes prescribed them

Figure 9. Restoration of the Université Paris 4 Building, Paris

remarks in 1924 "*the problem becomes one of two buildings with the vertical circulation of the top building running through the lower as an express service*" (Corbett, 1924). With the introduction of this system, the problem of the maximum economic height was even more pronounced than before. If the site forced the erection of very tall towers, in order to attain the commercial square footage necessary to cover the investment, buildings thus required a growing number of elevators. This reduced the Net Rentable to Gross Floor Area ratio (NRA/GFA). The exact equilibrium point of such a system became crucial for the financial and functional success of a skyscraper. This situation influenced the economic and functional balance of tall buildings until the 1960's, imposing a height limit linked to a building's functionality. Several documents dating back to the 1920's (such as those reported in Willis's "*Building the Empire State*") (Willis, 1992) describe the real estate speculators' complex calculations (Clarck & Kingston, 1930) anticipating the construction of a skyscraper.

The service core was then located in the most efficient position inside the tower. In the case of large buildings (Empire State Building, Chrysler Building etc.) it occupied a central position surrounded by a ring of offices. In the case of smaller towers (built on small parcels, like the City Bank Farmers in New York), the service core was placed on one side of the building, as its central location would have created offices too narrow to be efficiently exploited (see Figure 8).

However, despite the increased height of towers, no structural innovations were introduced during this period, and buildings relied on the abundant use of structural materials rather than on an efficient structural form (Ali & Moon, 2007).

The Modern Service Core
A proposed definition

After the multitude of towers built following the establishment of the Zoning Law, the evolution of the service core came to a halt. After a 50-year long evolution that was concluded in the early 1930's, the service core of a tall building can be defined as, "*An element that gathers together the spaces necessary to provide visual, physical and functional vertical connections that work effectively to distribute services through the building*" (Trabucco, 2008) (see Figure 9).

Technological innovations at the base of the modern service core

The crisis that struck the American economy in 1929 had a serious influence on the construction of skyscrapers. The giants from New York (Empire State Building and Chrysler Building) and some skyscrapers in Chicago built during this crisis, remained generally empty for many years, discouraging new initiatives. The impact of the crisis was so large that the Empire State Building generated more profit, during the first years, from its sightseeing observatory than from its office rental and it was therefore renamed by satirical press "*Empty State Building*" (Weisman, 1970). In America, despite a few earlier examples, the construction of tall buildings was resumed after the end of World War II, in the early 1950s. Nevertheless, during that period of crisis, some innovations have emerged to evolve the skyscraper. Air conditioning, efficient artificial lighting and the adoption of glazed curtain walls transformed this typology from "*the cathedral of finance*", as the Woolworth Building was often called, to the modern building image that has been diffused throughout the world to represent characteristically modern cities. "*In the 1950s, advances in technology and changes in architectural ideology liberated the tall office building from its dependence on nature and site. Fluorescent lighting and air conditioning were as important to the transformation of post-World War II skyscrapers as were the elevator and steel-cage construction to the first tall office buildings of the late nineteenth century*" (Willis, 1995).

Such innovations, together with the introduction of the glazed curtain wall, broke the dependency between the form of the building and the service core. These innovations, along with modifications to the building codes, allowed the creation of pure geometric forms that characterized the skyscrapers built in the 1950s and which were labeled the "*International Style*".

However, the connection between the service core and the building remained rather firm. The introduction of the completely sealed glass curtain wall made it necessary to develop more and more advanced systems of mechanical ventilation. Such a necessity required the use of large ventilation ducts, which were located inside the service core and thus increased its dimensions.

The Zoning Law system of setbacks was slowly being abandoned in favor of a more flexible system of trade-offs that allowed, in exchange for the provision of "*public amenities*" (open plazas, commercial spaces, metro entrances, etc.), the benefits of higher exploitation of the land. In New York, the modifications of the Zoning Law became official in 1961, despite being anticipated in numerous dispensations and exceptions, such as the Lever House and Seagram Building. Skyscrapers, no longer forced to fill the entire surface of a lot in order to obtain the maximum gain in terms of built area, began to provide space between each other. This disrupted the frontage continuum and created pedestrian areas along their perimeters. As a result, a remarkable increase in the value of the lots occurred. A skyscraper, isolated in the center of the lot, could benefit from an internal organization of offices facing outward on all 4 sides with open views all around.

The introduction of the glass curtain wall and the desire to maximize outward views, resulted in the relocation of the bracing system towards the center of the building . Therefore, many service cores became the fundamental structural element of the whole tower. Indeed, the role of SOM's engineer Fazlur Khan in the diversification of tall building structures should be acknowledged. He demonstrated that the rigid frame structure used since the 19th century was not the only structural scheme available for tall buildings and that more efficient structures could be used. 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*" (Ali & Moon, 2007). On exterior structures the lateral load-bearing system is contained in the structural elements on the building's perimeter (such as in tube structures), as opposed to the interior structures where such elements are within the building's perimeter, notable in a structural shell that encircles the service core.

As a consequence, in many cases the service core acquires (internal structures are more diffused than external ones) the important function of bearing the lateral loads acting on the building. The service core's dimensions, in many cases dictated by structural requirements, tended to generate a geometrically regular form, containing all of the typical service core functions inside. Main and secondary are thereby enclosed in a well-defined location formed by the core's structural elements and are fire-protected as required per code. In addition, the service core hosts the whole exit means from the building in case of danger. Though the use of stairs is still considered the most reliable method of escape, fire elevators are now getting more and more common, since the presence of super-tall buildings and post-9/11 fears actually requires faster evacuation strategies. For this reason the elevator industry is now proposing fire elevators that can be used under specific circumstances and special design conditions, for faster evacuation of the building (Bukowski, 2005).

With the introduction of different lateral load bearing systems after the 1960s, the service core concluded its process of morphological and functional development. This process followed step by step, and often influenced, the evolution of the skyscraper itself. It has finally brought the service core to assume its characteristic central position within the building.

Toward a New Idea of Service Core

In the last few years, a new wave of innovations to service core design has been related to sustainability-issues. The promoters of these trends are different from the traditional ones, who were formerly represented by the final users, the industry or the developers. The new key figures that are driving the innovations trend have been architects. In fact, it should be acknowledged that figures such as Ken Yeang and Norman Foster (among many others) are in the forefront of innovative development of the tall building typology as a whole, and of the service core in particular. Architects are reacting to the stimulus of sustainability more than the other players of the building process. The service core will then be credited an additional value, and more functions are going to be added to its elements.

Figure 10. External service core of One Bush Street in San Francisco

Future trends of development will be mainly focussed on displacing the service core from its traditional central position in the building plan. Peripheral or external service cores, moved to the sunny side of the building, will more often be used for shading the occupied spaces. Early examples of this trend are to be found in SOM's Inland Steel and One Bush Buildings, located in Chicago and San Francisco, respectively. Both were built in the late 1950's, although in these examples the external core had other purposes than shading (see Figure 10). More modern examples of external service cores, built with the explicit purpose of shading the building (Yeang, 1991), are many of Ken Yeang's skyscrapers such as the Menara Mesinaga, the Menara Boustead and the IBM Plaza (see Figure 11). Another recent case is SOM's Poly Complex in Guangzhou. In this case "*the drawbacks arising from an unconventional design and placement of the service core require to be carefully evaluated*" (Trabucco, 2008). This is especially true for the increased embodied energy of the building that comes along as a consequence of the diminished NRA/GFA, even though some exceptions must be considered (Jahnkassim & Ip, 2006). External service cores can provide a valuable option in those climates where natural ventilation is viable for most of the year (Pedrini, 2003). In fact, the external service core can be naturally ventilated, thereby diminishing the total volume to be mechanically conditioned. Furthermore, the external location of elevators, toilets and other mechanical rooms can

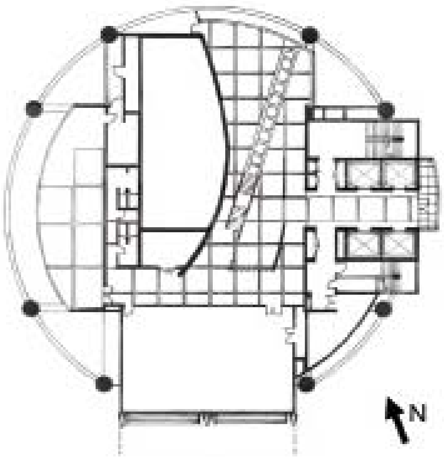

Figure 11. Menara Mesiniaga in Kuala Lumpur. The service core shades the building protecting it from the solar radiation. © T.R. Hamzah & Yeang Sdn. Bhd

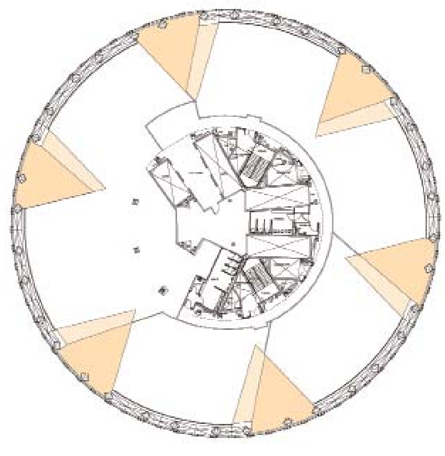

Figure 12. Swiss Re Tower, London. The Ventilation voids can be considered as part of the service core

mitigate the influence of the heat loads they usually generate.

A border-line example of the modern service core, accordingly to the definition provided, is represented by the spiraling voids cut in the tiers of Foster's Swiss Re Tower (see Figure 12). Despite their not being part of a compact body, they work effectively to distribute natural ventilation through the building. By comparison, they provide the same effect of the vertical voids of Thomas Herzog's Messe Tower in Hannover. Even though the voids designed in the 18-story building are enclosed in more conventional shafts while those in Foster's building are completely opened in the floors' volume, their functioning is based on the same principle.

The future evolution of the service core can then be summarized under three headings, according to the final effect achieved:

- Shading: External service cores, more suitable for cooling-intensive buildings (according to climate and external contraints)
- Thermal Inertia: Service cores on the building's perimeter, can be used on the sunny side of a cooling-intensive building or on the north side of buildings in very cold and windy locations
- Natural ventilation: Internal service cores, featuring large voids that are used to promote a natural movement of the air through convection/Venturi effect.

Architects are now encouraged to think "*outside of the box*" for the whole design process, looking toward many more complex possibilities for the design of the service core (Yeang 2006).

The financial crisis that has halted the tall building industry will probably cut out most of the "*eccentric*" projects recently proposed. Post-crisis buildings will have to be built with substantially lower budgets that will hopefully prevent excessive "*iconic*" solutions. A smarter design is the path to follow to build good-quality, low-budget skyscrapers. Advanced service core design could be a good starting point (Ali & Armstrong, 2008; Pank, Girardet & Cox COX, 2002).

"An evolution still in progress"

The analysis of the history of the service core presented by this paper offers the possibility to look at the evolution of tall buildings in a new way. The first skyscrapers that appeared in New York and Chicago, during the second half of the 19th century, were affected by stringent constraints imposed by the lot dimensions, the lighting needs and other economic considerations. They produced two different typologies of service cores that evolved autonomously. After Manhattan's Zoning Law of 1916, the vertical transportation system of the service core evolved into its actual form, with the invention of zoned towers, sky lobbies and double deck elevators. A structural evolution appeared only after recovering from World War II, in the late 1950s, when tall buildings abandoned the structural rigid frame scheme for more efficient systems. Thanks to F. Khan's work, the structures of tall buildings evolved toward a more effective use of materials. Therefore, the available structural schemes for tall buildings can be divided into internal and external structures, according to the position of the elements that carry the lateral loads, with the service core responsible for the structural resistance in the internal schemes.

The historic analysis of the evolution of the service core of tall buildings presented here is the introduction of a more comprehensive analysis on this part of a skyscraper. 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 (Ali & Armstrong, 2008). Service cores are often paid little attention by architects, since they are enclosed by the skin of the building and are packed with technical and mechanical devices whose design is usually controlled by highly specific professionals.

The author believes that much can be gained, in terms of economic and environmental sustainability, from a more integrated design process of all of its parts and from a different approach to its design. For example, with the surge of the issues related with the environmental sustainability of tall buildings, some architects have suggested a different location for the service core: this action is expected to have a positive influence on the thermal control of the building. On the other hand, this design strategy is likely to cause an increase of the dimension of the whole building, since i.e. longer corridors are needed for distribution. An interesting research topic is whether the consequence on the embodied energy of the whole structure can offset the benefits obtained with a better thermal control of the building. ■

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