BUDAPESTI MŰSZAKI ÉS GAZDASÁGTUDOMÁNYI EGYETEM

Építészmérnöki Kar

Épületszerkezettani Tanszék

Tall buildings and Sustainability: comprehensive review supported by a practical case study

Szerző: **Bakos Bálint**

Építészhallgató

BME

Konzulens: **Dr. Reith András**

Ügyvezető

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Abstract

The author is aiming to provide a thorough review on today's high-rise sustainability with an outlook to future prospects. High-rise buildings, tall buildings and skyscrapers are a daily topic of scientific and public discussion, however there is no globally accepted, crystal clear definition connected to any of these terms. The most important factors leading to the birth of tall buildings are well known, however the factors extensively influencing the evolution of these buildings are rarely discussed. There are only a few typological aspects used in literature related to tall buildings, however there is a strong research potential resulting the mixing of several typological aspects into a complex matrix along a logical line.

Along the emergence of global environmental awareness, there is a very strong architectural trend forming around the topic of green building and sustainability, already resulting in a big 'green race' between new building projects. As tall buildings are of the most emblematic structures incorporating cutting edge technology, their potential of raising public awareness and shaping global sustainable construction trends is enormous. The terms Green design and Sustainable design are often used inaccurately, interchangedly and mixed up with other terms, such as ecological design, bioclimatic design, natural design, solar design, passive design, net zero energy design and so on. Green is not necessarily sustainable and vice versa, although there is a strong relationship between them. Climatic conditions are also a very important aspect, since they fundamentally influence the appropriate set of design tools and long term building performance. There are numerous evaluation practices on the market; however none of them are complex enough to cover all the main aspects leading to sustainability. There is no currently available tool designed specifically for tall buildings. There is lack of data about certified buildings' real energy use. Global legislation in this field has not yet reached enough maturity to form a frame of laws forcing building owners to publish data on energy use characteristics. Certified buildings without proven efficiency are misleading the public and generate global distrust. The theoretical existence of sustainable tall buildings is still globally argued, despite the numerous arguments and projects aiming to provide final evidence in favor. There are numerous recently born aspects of design methodology playing highly important role in achieving the objectives of sustainable architecture. A case study is provided by the author in order to highlight some of the reviewed aspects of tall buildings' green design and sustainability. Rough quantitative results of life cycle energy analysis and life cycle cost analysis show the long run feasibility of the required design changes, however - due to external factors from the client's side – numerous aspect of sustainable design remain unfulfilled.

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1. Tall buildings

1.1.Terms in close relation

High-rise buildings, tall buildings and skyscrapers are a daily topic of scientific and public discussion, however there is no globally accepted, crystal clear definition connected to any of these terms.

Professions related to the topic possess different terminologies, terms of which are often mixed and falsely interchanged in the public discussion. On the other hand there are custom terms, long time used by the public with blurred or non-existent definitions. This is resulting in a general confusion not only for someone new to the topic but for professionals as well.

As the present study is based on the topic of high-rise buildings, it is necessary to 'wipe the table', providing a scope for the upcoming discussion by sufficiently defining the basic terms. Less important terms linked to the topic, such as towers or skyprickers are not discussed here.

Figure 1 – Tall building in clouds (Photograph by Sebastian Opitz, source: 123inspiration.com)

High-rise buildings

According to today's biggest online building database, a high-rise building's architectural height is ranging between 35 and 100 meters. If the height is unknown, a building at least 12 floors or fewer than 40 floors is considered to be a high-rise.(Emporis 2013)

As we are looking inside the 2012 International Building Code commonly used throughout the United States, we find that a high-rise building is to have an occupied floor at least 75 feet (approximately 23 m) above the lowest level of fire department vehicle access.(International Code Council 2011) However the term high-rise building in everyday language is often just referring to "A multistoried building equipped with elevators."(Pickett 2006), embracing a more significant proportion of buildings.

Two out of the three above cited definitions are not specifying an upper limit of architectural height while all of them are defining a minimal height criterion, even though a multistoried building's minimal height can not be precisely quantified. An occupied floor 23 meters from street level is assuming an architectural height[1] of at least 25 meters. Deriving from these facts a simplified definition for the term high-rise buildings could be proposed: *A high-rise building is a building with a minimal architectural height of 25 meters.*

1.1.1. Skyscrapers

The word skyscraper was born in the 19th century United States, where – following a series of engineering innovations – relatively tall buildings of 10-20 stories were constructed. In everyday use, a 'skyscraper' is "a very tall building with many stories" (Stevenson 2010), scraping the sky, often endlessly vanishing away in the stream of clouds. Emporis Standards Committee is defining skyscrapers as multy-storey buildings with an architectural height of at least 100 meters, (Emporis 2013) however these days we rarely call anything less than 50 storeys a skyscraper (Sonder 1999). On the other hand, a building can only be called high relative to its context; therefore a 20 storey building could be called a skyscraper in a single storey neighbourhood while it would look rather small in Manhattan.

A different approach is based on structural considerations, defining the skyscraper by opposing its structural system to buildings with load-bering walls. Along this way it could be

[1] Height is measured from the level of the lowest, significant, open-air, pedestrian entrance to the architectural top of the building, including spires, but not including antennae, signage, flag poles or other functional-technical equipment (CTBUH 2013b).

proposed to look at skyscrapers from the structural point of view and draw the line where the structural design is significantly affected by lateral rather than vertical loads (Taranath 2010). Considering the above mentioned and the fact that the relative height of tall buildings witnessed a considerable growth troughout the years; resulting in a slight transformation of public sense for "tallness", the term "skyscraper" could be appropriate to be used for buildings taller than 150 meters.

1.1.2. Tall buildings

Not surprisingly there is no global consensus about an exact height criterion for tall buildings. A common classification around the world is based on the maximum reachable height by available firefirghting equipment (Beedle 1977). According to ASHRAE (American Society of Heating, Refrigerating and Air-conditioning Engineers), tall buildings are higher than 300 feet or 91 meters, which is clearly overtaking the range of other height criterias (ASHRAE 2013).

Fortunately the term tall building has been taken care of, and thoughtful effort was made to define it by the Council of Tall Buildings and Urban Habitat (CTBUH), a joint group originally founded in 1976 by Lynn S. Beedle.

CTBUH is offering three evaluation categories along which we can decide whether a building can be called tall or not. The first category is the building's height relative to its context, which is quite important as we might call something tall in a European city although it could hardly be considered tall in Hong Kong or Manhattan. The second category is about the proportion of the building, as two buildings with the same height look very different if one is slender and the other one is rather robust with a big floor area. The third category addresses certain building technologies which are tipically connected with tall building projects, such as special elevator technologies or structural wind bracings.

Apart from the above categorization CTBUH offers a thumb rule based on actual height, calling a building featuring at least 14 storeys or 50 meters (165 feet) height a tall building.

Other terms associated with the organization are"supertall" and "megatall" buildings. Supertall buildings are ranging between 300 and 600 meters in height while megatalls are over 600 meters. As of July of 2013, 73 supertall and 2 megatall buildings are completed globally (CTBUH 2013b).

1.1.3. Making it simple

Simplifying and more importantly clarifying terms is necessary regardless to whether they are used in public or professional language. Based on a brief review of the current diffuse terminology, the following, simplified definitions are to be used in the present study:

1.) High-rise building: *A building with a minimal architectural height of 25 meters.*
2.) Skyscraper: *A building with a minimal architectural height of 150 meters.*
3.) Tall building: *A building with a minimal architectural height of 50 meters, and either (a.) clearly tall relative to its context, or (b.) the slenderness ratio (length/width) is at least 4; or (c.) contains building technologies which are results of great height or significant lateral loads.*
4.) Supertall building: *A tall building with an architectural height between 300 and 500 meters.*
5.) Megatall building: *A tall building with a minimal architectural height of 600 meters.*

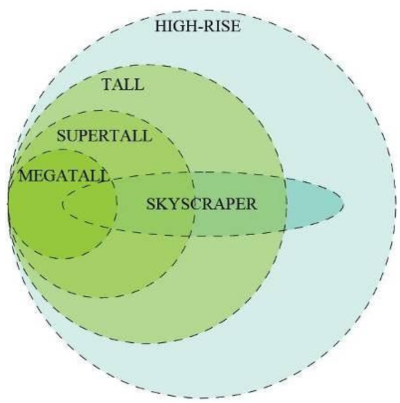


Figure 2 – Proposed high-rise terms in graphical sets (graph by author)

1.2. The emergence of tall buildings

A good source of various literatures is out there about the emergence of tall buildings. The topic is wide ranging, deeply connected to the global history of architecture, engineering, economy, society and politics. It is also very inspiring for one to look at all the innovation, changes and development going on through the 19th and the early 20th centuries which realized the roots of this building tipology. In the present study, however, my goal is limited to highlight the most important factors influencing the birth of tall buildings.

It is important to highlight that tall buildings were not just born from one day to another; they are a result of the complex interaction of many events, however in terms of classification we have to draw the line and name a 'first skyscraper ever', the building first incorporating all the necessary features of an early skyscraper.

Based on my research, three types of main drivers could be named fostering the emergence of tall buildings in the second half of 19^{th} century: *social, economical* and *technical*. The prosperity of New York and Chicago were greatly attractive for people, resulting in thousands and thousands of people leaving rural areas to move into these cities in their pursuit of wealth and happiness, forming the *social driver* for a denser and vertically expanded built environment. As the population was rapidly growing, demand appeared towards more and more floor area for living and working, driving the property prices exceptionally high; therefore *economically* pushing architecture "to new heights". On top of these factors, the 19^{th} century was one of the most inventive periods in human life, giving birth to new ideas which finally made tall buildings reality.

1.2.1. Technical innovations leading to tall buildings

The birth of skyscrapers can be directly associated with the development of structural systems. Taller structures are heavier; hence they need stronger foundations piled into the stiff bedrock, which would have been impossible without the invention of steam powered drilling and digging machines in the 1830s(Skyscraper 2013). Economically favorable, mass-produced rolled steel became available after 1856 through Henry Bessemer's invention. The so called *"Bessemer process"* enabled the emergence of cage- and skeleton-frame structures(Ali & Armstrong 2010)(Britannica 2013a). Top floor offices were not attracting tenants until buildings were equipped with safe elevators, thanks to Elisha Otis's safety elevator, invented in 1854 and patented in 1861(Britannica 2013b). The Equitable Life Assurance Building in New York – completed in 1870 - was the first office building to use passenger elevators. It is also by many considered the first skyscraper despite its mixed bearing-wall system(Friedman 2012)(Robins & Young 1996). Fireproofing became a big issue in the 1870s, after Chicago and Boston experiencing serious fires in 1871 and '72. As Chicago's complete city center was destroyed by the fire, wooden structures had to be replaced mostly by fireproofed steel. Peter Bonnett Wight was one of the researchers and publishers of new approaches in fire safety. The 70's were fertile years as electric lighting and steam-driven, forced draft ventilation systems became available in buildings, breaking down the least barriers to safe and comfortable tall buildings(Condit & Landau 1996). Some of the important inventions and pioneering buildings are presented in the graph below. (Figure 3)

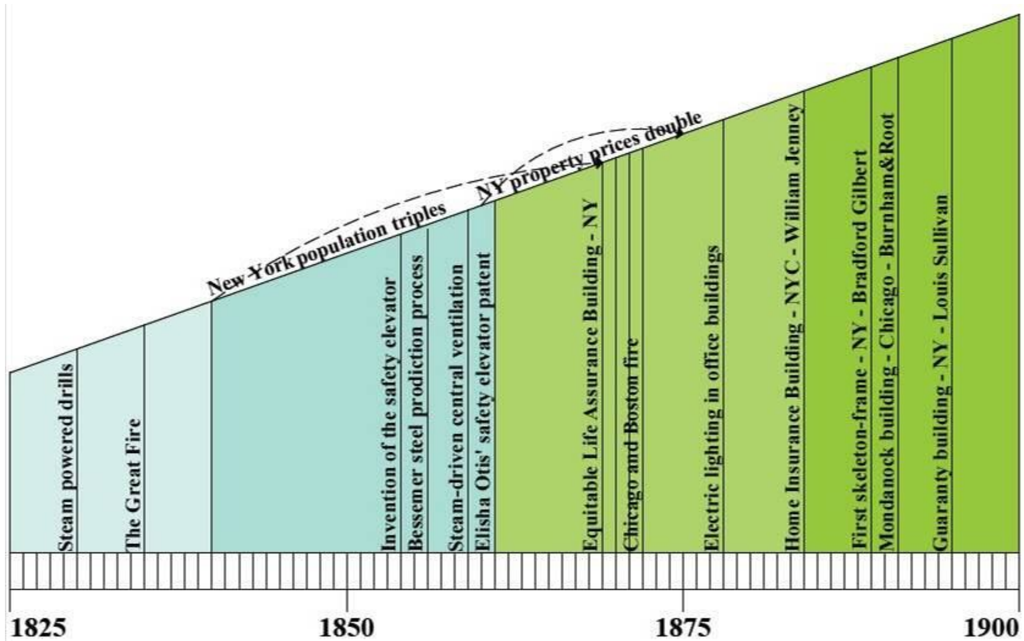


Figure 3 – 19th century early skyscrapers timeline (figure by author)

The 19th century – as stated above – was one of the most inventive parts of human history. The field of structural engineering was also in an extensive development. New types of foundations, fire resistant structures, wind bracing, emergence of cast iron and steel, curtain walls and many other steps of technical development arose. Low-rise bearing-wall masonry structures started aiming into new heights. As height increased – though -, walls got thicker and thicker, resulting in extensive floor space loss. Masonry construction is said to be on its peak upon the 1891 construction of the 17 storey, 64 m tall Monadnock building in Chicago with a painful 15% of the groundfloor area taken by walls only(Taranath 2010). Well before this time, structural engineers already started incorporating cast iron frames into their bearing-walls, resulting in mixed bearing-wall buildings, shown by the case of formerly mentioned Equitable Life Assurance Building. Today's well distinguished terms, cage-frame and skeleton-frame were interchangedly used in the late 19th century, resulting in Chicago's and William Le Baron Jenney's Home Insurance Building (1884) winning today's title of "the first skyscraper". The Home Insurance Building reached an impressive 10 storeys and 42 meters height, however the structural system was not a skeletal frame yet, "only" the first completed cage-frame (Friedman 2012). Finally the first believed true skeleton-frame building was built in New York, in 1889. The designer, Bradford Gilbert proposed this structural solution because a masonry construction would not have left any usable floor area on the exceptionally narrow plot(Dolkart 2013). Figure 4 is comparing common structural systems of early skyscrapers.

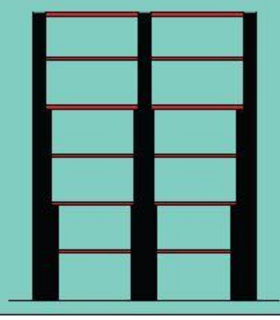
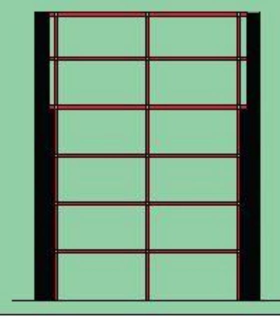
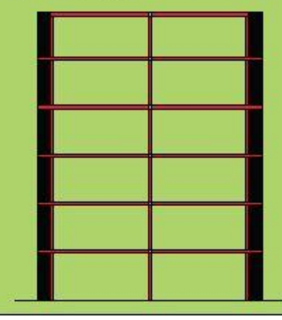
	Bearing-wall	Cage-frame	Skeleton-frame
Gravity support	walls	exterior walls - walls floors - frame	frame
Lateral bracing	walls	usually by walls	frame
Enclosure	walls	walls	walls
Usable floors	planks laid over joists or flooring laid over masonry vaulting	flooring laid over masonry vaulting	flooring laid over masonry vaulting or concrete slabs
Fire-protection	only partially solved - walls, plaster ceilings	exterior walls and masonry vaulting	exterior walls, masonry or concrete floors, fireproofing explicitly applied to the frame
Illustration			

Figure 4 Structural systems through the 19th century (figure by author, based on (Friedman 2012)**)**

By the turn of the century, the cloud of technical limitations slowly disappeared. Pioneering cities kept flourishing and hunger for tall buildings was incredible. Skyscrapers were very impressive for the public as well, leaving no hesitation for developers to come up with new ideas. Like greyhounds set free on track, 20th century skyscrapers started the race for being the tallest in the world. (Figure 5)

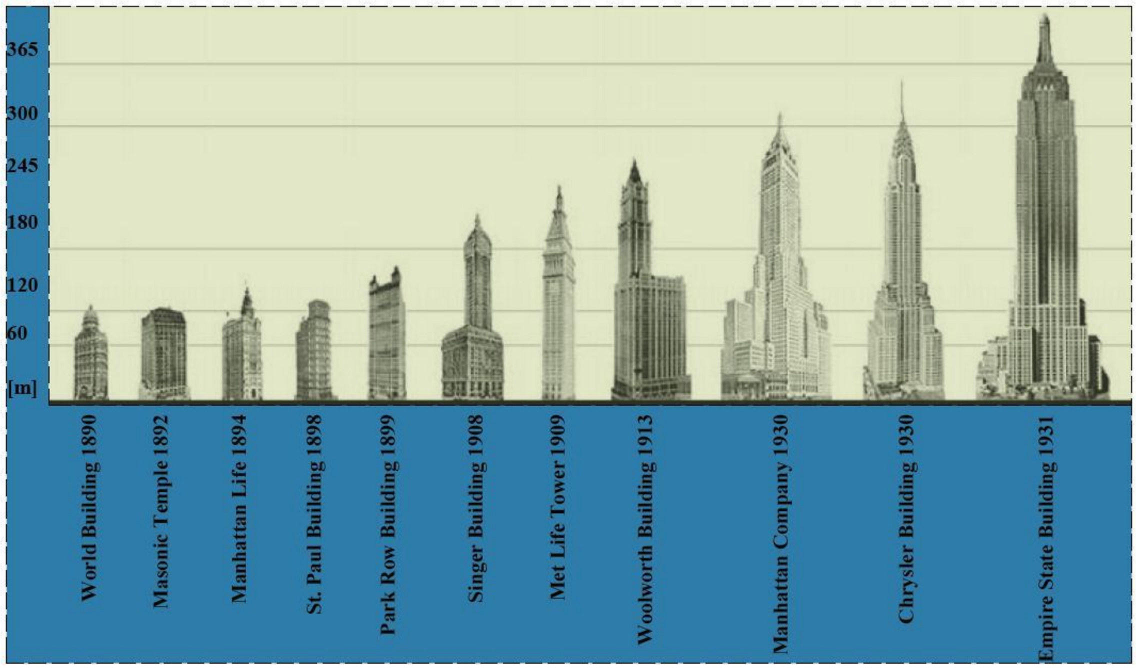


Figure 5 – Pre-Second World War tallest buildings (edited by author, source: skyscrapermuseum.org)

1.3. The evolution of skyscrapers

"The architects of this land and generation are now brought face to face with something new under the sun,-namely, that evolution and integration of social conditions, that special grouping of them, that results in a demand for the erection of tall office buildings. It is not my purpose to discuss the social conditions; I accept them as the fact, and say at once that the design of the tall office building must be recognized and confronted at the outset as a problem to be solved,- a vital problem pressing for a true solution." (Sullivan 1896)

1.3.1. European influence

"It was a curious situation: on the one side American architects and clients clamouring for the instant sanction of European culture; on the other a European avant-garde looking romantically to America as the promised land of all things modern." (Curtis 1996, pp. 218)

Many – later prominent - American architects of the early 20th century traveled overseas to study in Paris, adsorbing the French taste of neoclassical architectural style named Beaux-Arts (Richardson, Burnham, Gilbert, White, McKim, Sullivan, etc.). The Parisian school was greatly influential on the United States' architecture, resulting in most of skyscrapers built in this style until the first few decades of the 20th century.

"*…when our architects shall cease strutting and prattling handcuffed and vainglorious In the asylum of a foreign school…when it becomes evident that we are merely speaking a foreign language with a noticeable American accent…*" Louis Sullivan (Sullivan 1896)

"*The New York skyline is a medieval atrocity. … Good architecture shouldn't have to depend on distance or the dark for its effects.*" Frank Lloyd Wright (Rodman 1961)

When it came to tall buildings, architects in New York did not invent a new approach to this building type, rather designed them in traditional styles, as they would do with any other buildings. This resulted in buildings like the Potter Building on Park Row, which was built in Queen Anne-style, a very common residential style using red brick and red terra-cotta. Good examples of Neoclassical style are some of the tallest buildings ever erected, such as the Park Row Building, finished in 1899 by R. H. Robertson; the later demolished 47 storey Singer building by Ernest Flagg; or the 213 meters high, 50 storey Met Life Tower finished in 1909. Earning the tallest building title for 17 years upon its 1913 completion, the Woolworth Building was designed by Cass Gilbert in Gothic style(Dolkart 2013). (Figure 6) The "Neoclassical skyscraper", after a long fame in the US, finally disappeared in the 20s. Art Deco skyscrapers, such as the Chrysler Building or the Empire State Building – second of which remained the tallest building for more than 40 years – became the mainstream.

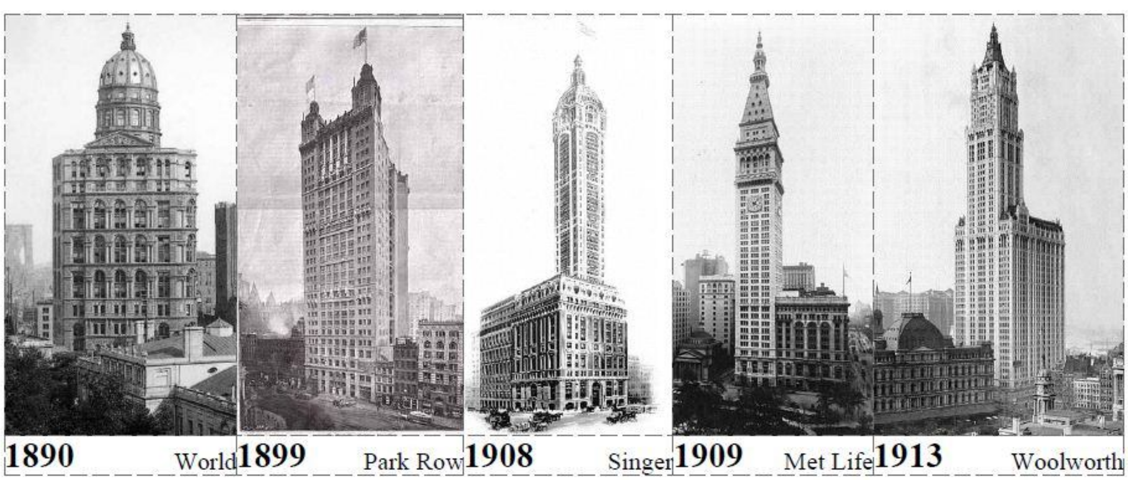


Figure 6 – New York Neoclassical skyscrapers (edited by author, source: wikipedia.com)

1.3.2. First Chicago School, Zoning law and Chicago Tribune Competition

"…Certain critics, and very thoughtful ones, have advanced the theory that the true prototype of the tall office building is the classical column. …form ever follows function, and this is the law … Shall we, then, daily violate this law in our art? … Does this not readily, clearly, and conclusively show that the lower one or two stories will take on a special character suited to the special needs, that the tiers of typical offices, having the same unchanging function, shall continue in the same unchanging form, and that as to the attic, specific and conclusive as it is in its very nature, its function shall equally be so in force, in significance, in continuity, in conclusiveness of outward expression? From this results, naturally, spontaneously, unwittingly, a three-part division,-not from any theory, symbol, or fancied logic."(Sullivan 1896)

Unlike New York architects, the Chicago School pursued a style very much related to the emerging Modern in Europe. The main characters of the school consisted of the most influential architects, such as William Le Baron Jenney, Dankmar Adler, Louis Sullivan or Frank Lloyd Wright.

Sullivan and Wright had a harsh opinions on Beaux-Arts style as they worked hard to invent something truly American. Wright's comment on the 1893 Chicago World's Fair "We can mostly thank to "uncle Dan" (Daniel Burnham) - who enthusiasticly supported Charles McKim and the others -, that the exhibition opened doors to the European Renaissance, and America became a great soil for the Parisian Beaux-Arts herds… ...The ambitious illiterates of the architectural profession were amazed America-wide. Experiencing the devastating craze of fam, my fear strengthened that they would set back American architecture at least fifty years."(Wright 1957, pp. 30)

Chicago School – at the end of the day - was very productive through the years: the Reliance Building, Monadnock Building, Wainwright Building or the "first skyscraper ever" Home Insurance Building all gloried their work (Curtis 1996, pp. 45-50).

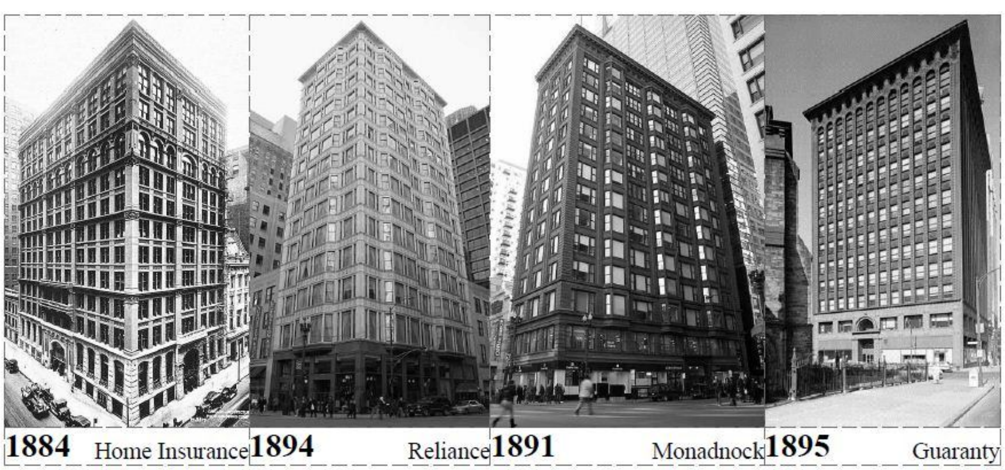


Figure 7 – Skyscrapers of the First Chicago School (edited by author, source: wikipedia.com)

As technical limitations were basically dissolved in front of building tall, nothing stopped developers to build higher and higher, occupying more and more floor area. In 1912 a truly speculative development to build a new Equitable Building was announced. The new building would take the entire plot and would be more than one million square feet area. In parallel, public concern rose about the lack of natural light penetration to streets surrounded by tall buildings. One year after the completion of the new Equitable Building, - in 1916 -, New York city introduced the first "Zoning law", which ensured that light and air would reach the street levels(Dolkart 2013).

Although Chicago did not have a zoning law, 1922's Chicago Tribune competition brought an outstanding design by Eliel Saarinen – inspired directly by the zoning law and the possibilities of architectural setbacks along tall building bodies. The Finnish architect's design was one of the most influential ones of those from the inter-war period.

The competition itself resulted in a broad range of architectural ideas clashing with each other proving the fact that there were no consensus on architectural sense in that age whatsoever.(Curtis 1996, pp. 220-223)

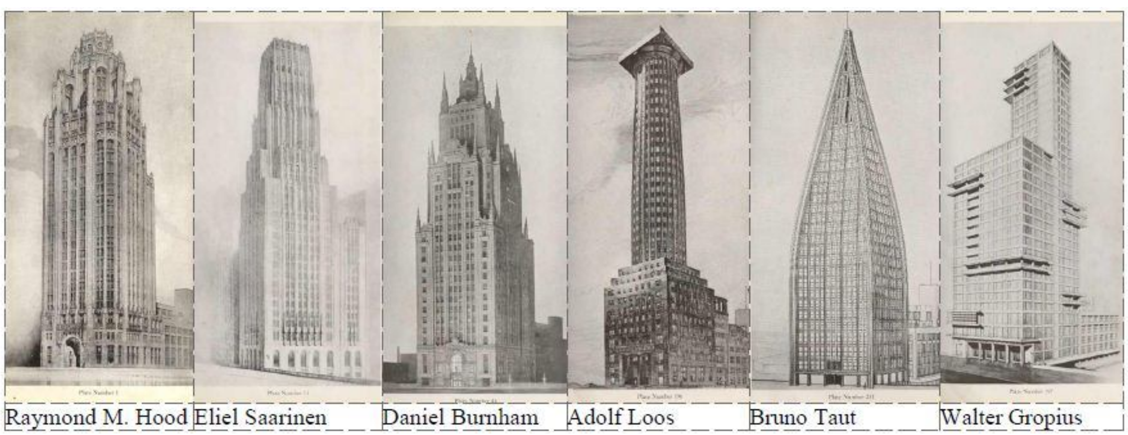


Figure 8 – Chicago Tribune competition entries (edited by author, source: skyscrapermuseum.org)

1.3.3. Modern architecture, Second Chicago School and International style

"Mies van der Rohe and Walter Gropius, for example, both arrived in the United States in 1937; Mendelsohn in 1941. They brought with them mature philosophies and vocabularies, and their arrival gave immense prestige to the International Modern movement in North America."(Curtis 1996, pp. 397)

Rooting from Neoplasticism and Deutscher Werkbund, influenced by De Stijl and Constructivism, - founded in 1919 by Walter Gropius – Bauhaus was on the way to set pillars for modern architecture. After more than 20 years of success, the school was forced to close by the Nazi regime. Many of the most recognized artists have then immigrated to North America in their pursuit of peace freedom. The Second Chicago School could finally emerge from the work of Mies van der Rohe, Fazlur Khan and other architects, which eventually led to the legacy of International style. Mies van der Rohe's contribution to tall buildings' evolution was great. By designing 860-880 Lake Shore Dr. apartments in Chicago (1951) and Seagram building in New York, he summarized in a very elegant fashion what we call today modern skyscraper design. Designed by an international board of architects, such as Le Corbusier or Oscar Niemeyer, the United Nations Headquarters in New York – upon its 1952 completion - was a perfect example of International style. Skidmore, Owings&Merrill (SOM)'s Lever House in New York(1952) also remarkably represented the movement.(Curtis 1996, pp. 407-410) The International style itself continued its legacy until the late '60s, the time of the construction of Minoru Yamasai's World Trade Center twin towers (1969).

Figure 9 – International style skyscrapers (edited by author, source: wikipedia.com/planet99.com/skyscrapercenter.com)

1.3.4. Postmodern, High-tech, Deconstructivism

“Philip Johnson is a highbrow. A highbrow is a man educated beyond his capacity.” Frank Lloyd Wright

As the glass box formula was reaching its downturn, new ideologies and directions emerged. They were not uniform, rather scattering to several ways of design, however each of them were somehow relying on ideologies from decades before.

Philip Johnson, previous collaborator of Mies van der Rohe, presented some of the most emblematically remaining buildings of this era. The New York based American Telephone and Telegraph (AT&T) building (1979) and “Lipstick” building (1986) - both set over classical ideas of form – could be traced back to Sullivan’s ideology of skyscrapers’ three vertical divisions.

Other directions, such as Hugh Stubbins’ Citicorp Headquarters - located a corner away from the Lipstick building –, or Javier Saenz de Oiza’s Torre BBVA in Madrid showed relation to the International style.

SOM’s Bruce Graham and Fazlur Khan seemed to be a great pair of architect and engineer, delivering the Structural Expressionist designs of Chicago’s John Hancock Center and Sears Tower (today’s Willis Tower), both being of the most emblematic skyscrapers ever built(Curtis 1996, pp. 558-559). Norman Foster’s HSBC Headquarters in Hong Kong – completed in 1985 – is a very classical example of structural expressionist, high-tech architecture; moreover it is already approaching a new direction in terms of open space, air and light. (Curtis 1996, pp. 658-659)

Figure 10 – Postmodern, Structural Expressionism, High-tech (edited by author, source: wikipedia.org; som.com)

Resting upon the philosophy of Jacques Derrida, Deconstructivism is challenging everything that is widely accepted as modernism, resulting in shocking disharmony and mistery. Many of today's star architecs were involved in Deconstructivism, such as Coop Himmelblau, Frank Gehry, Zaha Hadid, Rem Koolhaas, Daniel Liebeskind or Bernard Tschumi. (MOMA 1988)

Frank Gehry's 265 meters high 8 Spruce Street Building in New York is one of the built examples, featuring a very unusual fluctuating façade. Rem Koolhaas is directly aiming to "reinvent" the tall building by challenging the concept of conventional skyscrapers, which are only "extrapolations of single plans" The goal of his skyscraper designs is to integrate buildings within the city and create "social interaction instead of isolation" (Koolhaas 2008). Bejing's CCTV Headquarters - competed in 2012 – is displaying a very unusual approach to skyscraper massing, resulting in quite a disharmonic look. The building is probably Koolhaas' most published work, earning OMA the 2013 Best Tall Building Award of Asia.

The recently completed "Miniskirt" is also something extraordinary from OMA. The building is featuring a cantilevered multistory podium, 36 meters above street level(CTBUH 2013b). Some of today's young and successful architecture firms, such as BIG or MVRDV have also presented skyscraper designs with a sense of deconstructivism, such as the Cloud tower and the Cross tower(ArchDaily 2013). (Figure 11)

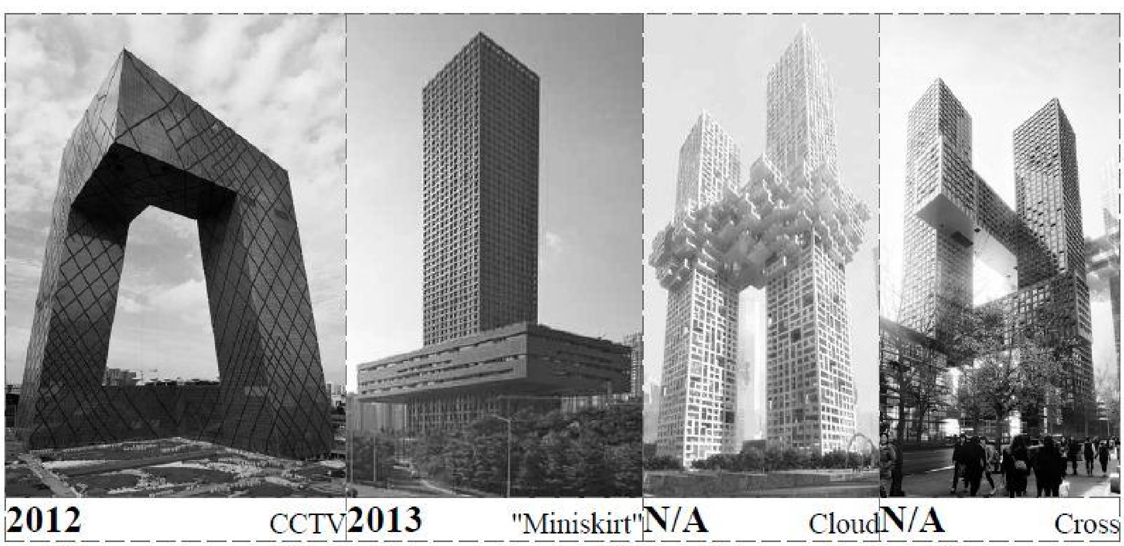


Figure 11 – 21st century skyscrapers with deconstructivist roots (edited by author, source: ctbuh.org; archdaily.com)

1.3.5. A new era?

In the past several years, one could notice a very strong new trend emerging around energy-efficient high-rise buildings, which employ various tools of green design and aim to eventually become "sustainable". Sustainable architecture is to be discussed later, yet, without any explanations we can highlight a few obvious reasons supporting its potential at the first look: It is something for a pure good reason – hence popular -; something cost-effective for the tenants; something that pays off for the developer; and – in the end – a slogan that can draw attention from the aesthetical value of architecture, often in defense of the creators.

As for buildings in general, can we degradate the idea of sustainability to call it a "style" of architecture? Are today's buildings "designed to be sustainable" exhibiting common aesthetical features? Can we even call single buildings sustainable? How could sustainable architecture be existent without its context? Among many others, the above questions are up on debate nowadays, waiting to get answered from the years ahead.

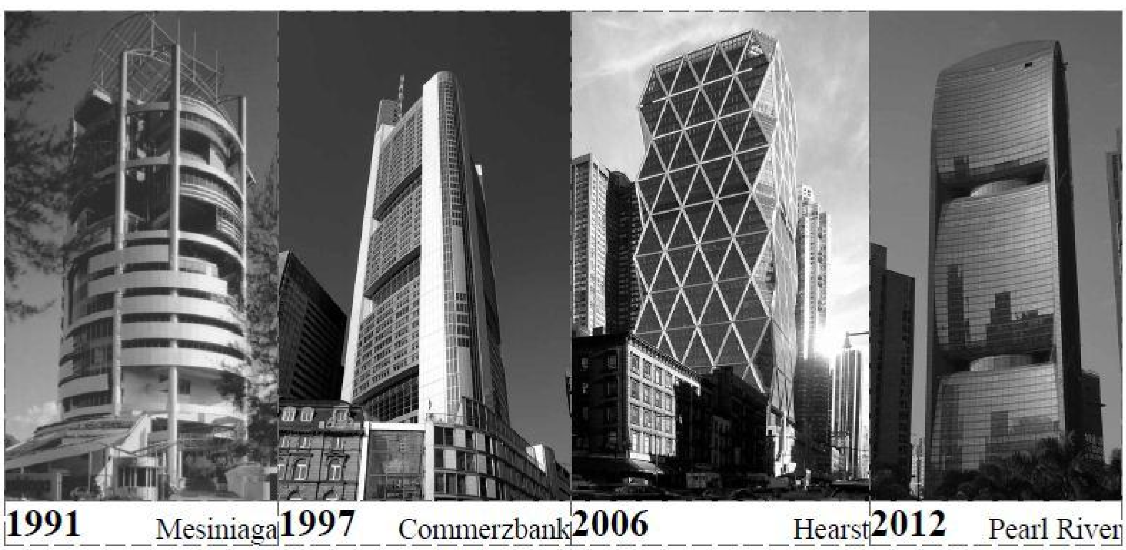


Figure 12 – High-rises with conceptual focus on sustainability (edited by author, source: ctbuh.org; wikipedia.com)

1.4.Categorization of tall buildings

We are soon to reach their 130th birthday; one can witness a dynamic flow of changes and development in almost every detail of tall buildings. There have been swings of architectural styles, new functions, materials and structural systems, social-, economical- and environmental aspects emerging, and finally, countless debates for- and against tall buildings. In light of the versatility and great number of built and functioning skyscrapers today, the raison d'etre of new classifications – in terms of research – is stronger than ever.

1.4.1. The classics

As it is the most distinctive feature of tall buildings, height is the most common aspect of classification. The race for being the tallest never stopped, however an uneven race with no rules is not much of interest anymore. Having previously discussed; terms "tall", "supertall" and "megatall" refer to the height-categories of high-rise buildings. (Figure 13)

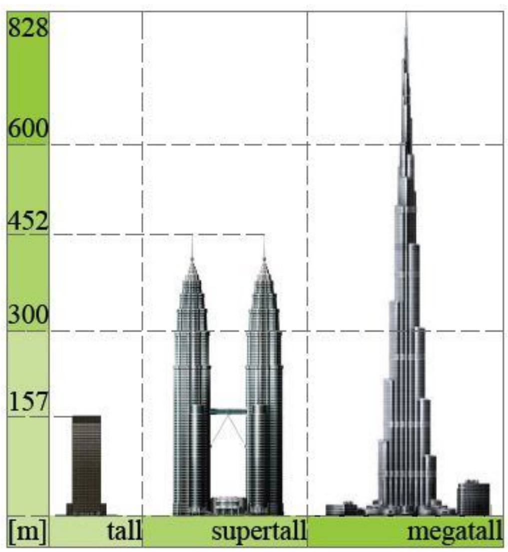


Figure 13 – Height comparison of Seagram Building, Petronas Towers and Burj Khalifa (edited by author, pictures: skyscraperpage.com)

In terms of function, CTBUH distinguishes two big categories, "single-function" and "mixed-use". If more than 85% of the building's floor area is dedicated to one function, then it is a "single function" building. In case of at least two functions, 15% of floor area or occupied floor number is dedicated to each; it is called a "mixed-use". The currently distinguished functions are office, residential and hotel(CTBUH 2013b).

According to CTBUH, the typological aspect of structural material currently divides tall buildings into four groups: steel-; concrete-; composite- and mixed-structures. A mixed-structure can be steel/concrete or concrete/steel, depending on which dominant material is located above the other. Composite structures are employing both concrete and steel, forcing them to "compositely" work together(CTBUH 2013b). Since the early issues with fireproofing and the emergence of steel and concrete, one is automatically taking only these materials into consideration when it comes to tall buildings. A new research project of Skidmore, Owings&Merrill is however investigating a completely new structural system from the combination of timber and reinforced concrete, called "Concrete Jointed Timber Frame". The main idea is to use timber's advantage to reduce carbon footprint by 60-75%. Although further research and physical testing is required, the current solution is stated to be technically feasible(SOM 2013).(Figure 14)

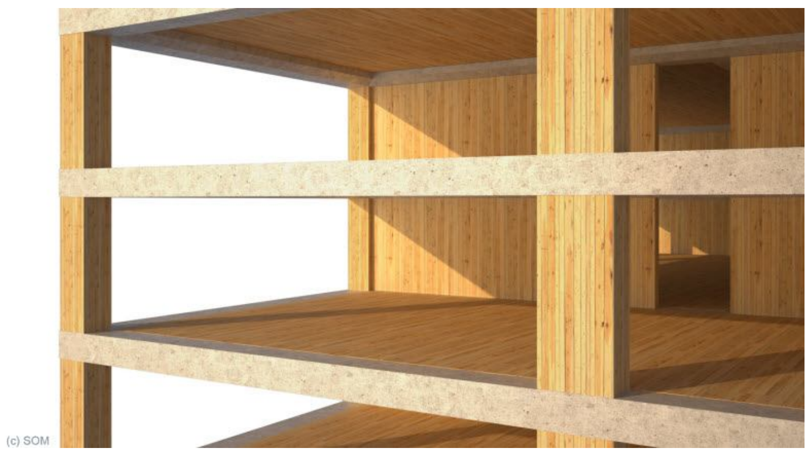


Figure 14 – Timber Tower Research Project visualization (source: som.com)

Structural systems have witnessed tide-turning evolution through the years. According to Taranath(2010, pp. 685-687), three major type of tall building structures have been employed in the last 120 years. In the first category, gravity loads are carried by the exterior walls; the second type uses frame structures with curtain walls, while the third type is consisting of a perimeter tubular structure supplemented by an inside service core. SOM's legendary Fazlur Khan – around the completion time of John Hancock Center - published schematic diagrams for possible tall building structures according to height, based on which Ali and Moon (2007) presented today's probably most recognized classification.

They divide tall building structures into two main categories; "interior structures" and "exterior structures" according to the location of the primary lateral load-resisting system. In terms of interior structures, they distinguish five categories: ***rigid frames***; ***braced hinged frames***; ***shear wall systems***; ***shear wall-frame interaction systems*** and ***outrigger structures***. (Figure 15) Exterior structures are also divided to five groups: *tube systems*; ***diagrid systems***; *space truss structures*; *superframes* and *exo-skeletons*. (Figure 16)

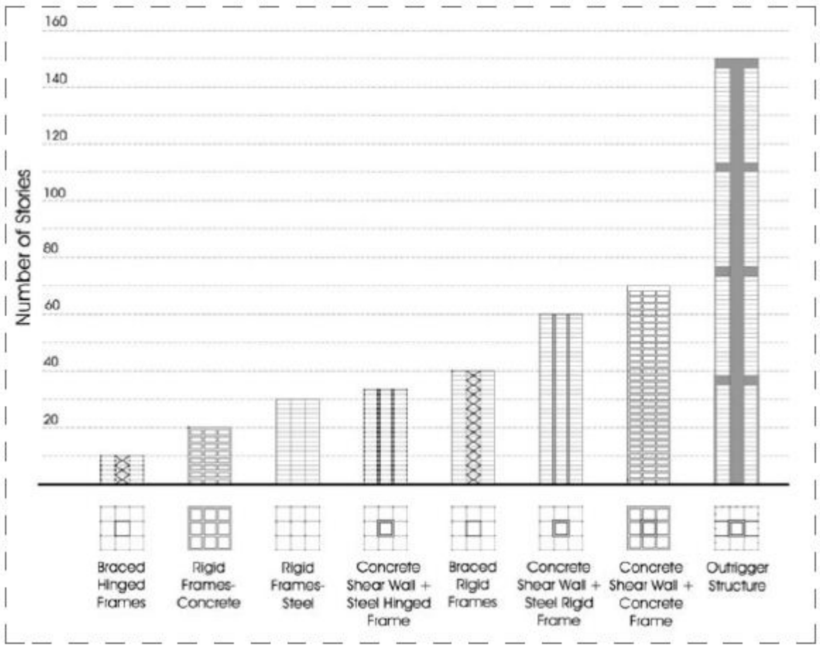


Figure 15 – Interior structures (edited by author, source: (Ali & Moon 2007)**)**

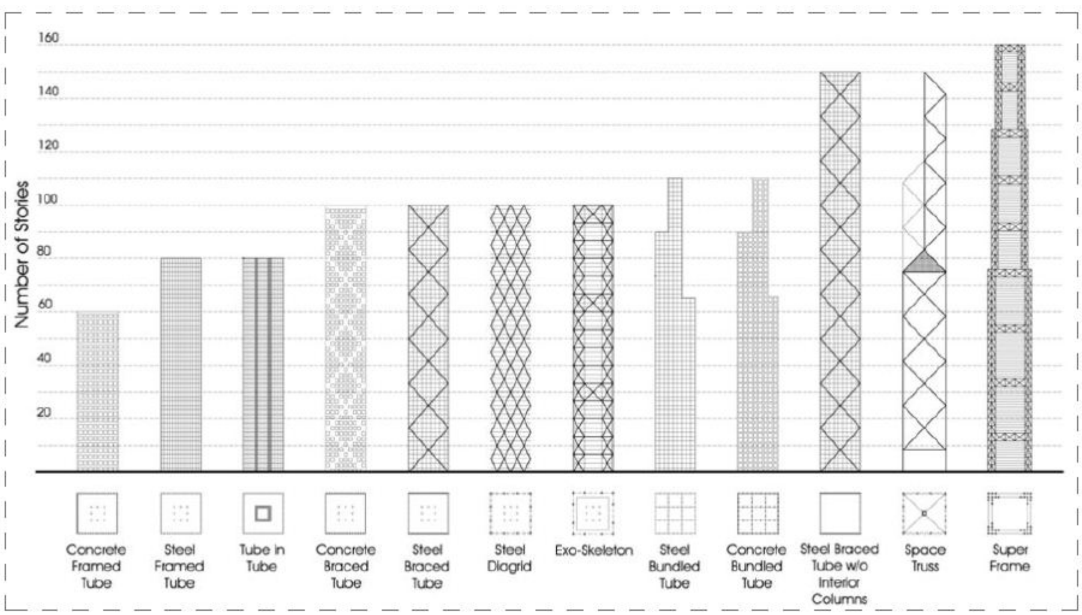


Figure 16 – Exterior structures (edited by author, source: (Ali & Moon 2007)**)**

1.4.2. Newcomers

There are numerous new approaches to the classification of tall buildings today. According to one's research purpose, there are countless opportunities in taking one or more aspects into consideration and compare tall buildings according to these new classifications.

A recent study published through CTBUH is creating a new term "vanity height" by assessing the unoccupied proportion of tall buildings(CTBUH 2013c). The results are a good support for the ones thinking that final height of tall buildings, after all, depends on ego(Ronald 2008).(Figure 17)

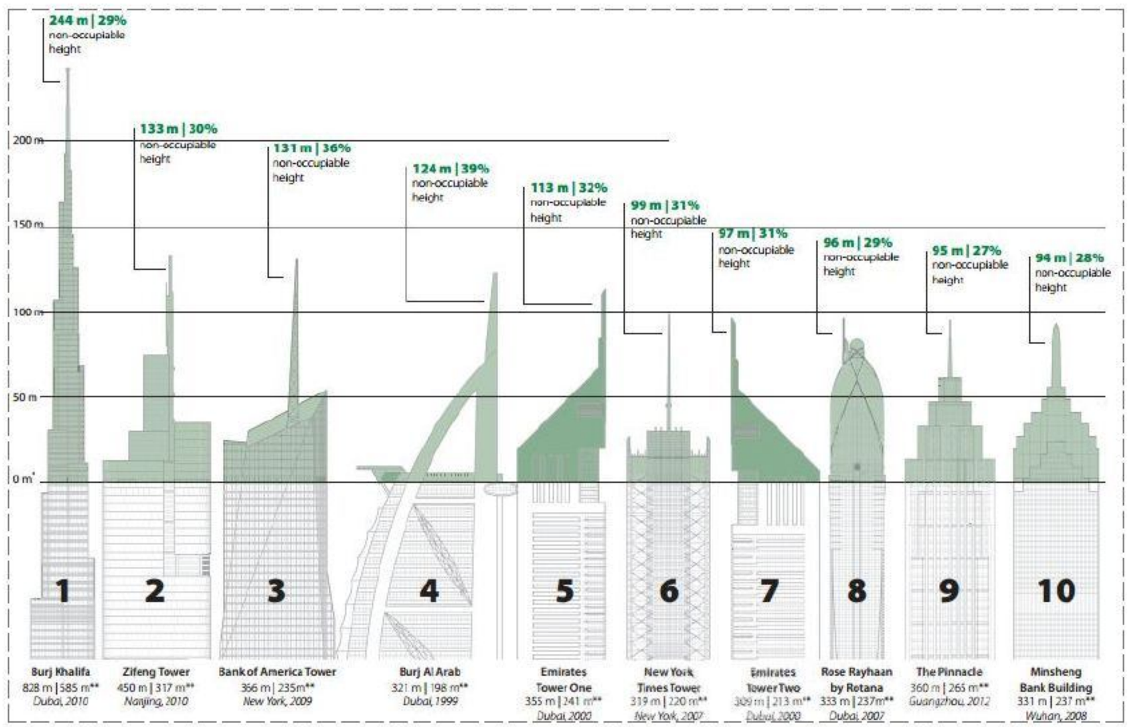


Figure 17 – Vanity height of tall buildings (CTBUH 2013c)

A research more of professional interest than the previous one is about the wall/floor ratio of tall buildings paired with their location. Wall-to-floor ratio indicates the proportion of wall area for each sqm of GFA (Gross Floor Area). The smaller the number, the more floor plate goes for the same façade area, resulting in less "physical contact" with the environment: darker spaces and smaller GFA/conditioned volume – and also averagely cheaper buildings. The results show a strong difference between the floor ratios of examined European and Asian skyscrapers. In case of Europe(particularly London), numbers range from 0.30-0.64

with an average of 0.49; while in Asia they average 0.33 with a narrow range of 0.30-0.34(Watts & Kimpian 2012).(Figure 18)

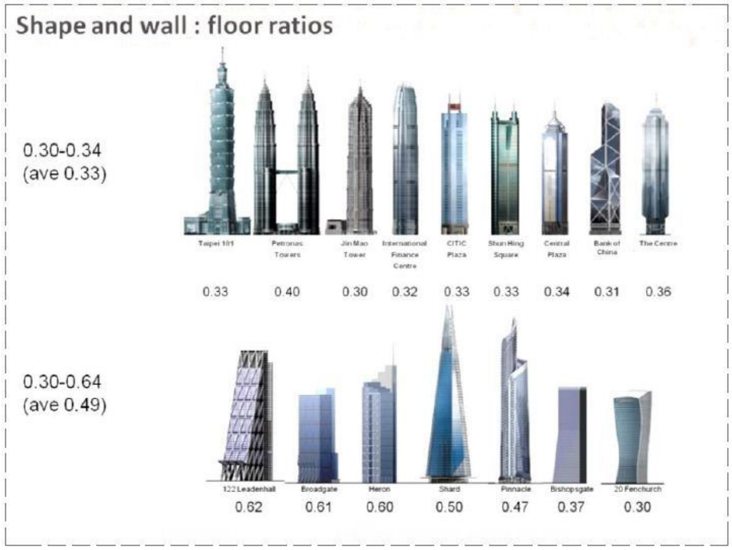


Figure 18 – Shape, wall-to-floor ratio and location – (Source: (Barton & Watts 2013)**)**

Not much of surprise, the geographical location and construction cost of tall buildings also show a strong correlation, however these locations are considered rather in terms of economy than climate. The article is comparing five different locations in terms of “Shell and Core High-rise Construction Cost Range”, delivering a shocking result of Shanghai skyscrapers being almost 4 times cheaper as an average compared to the ones built in London(Watts & Langdon 2010). (Figure 19)

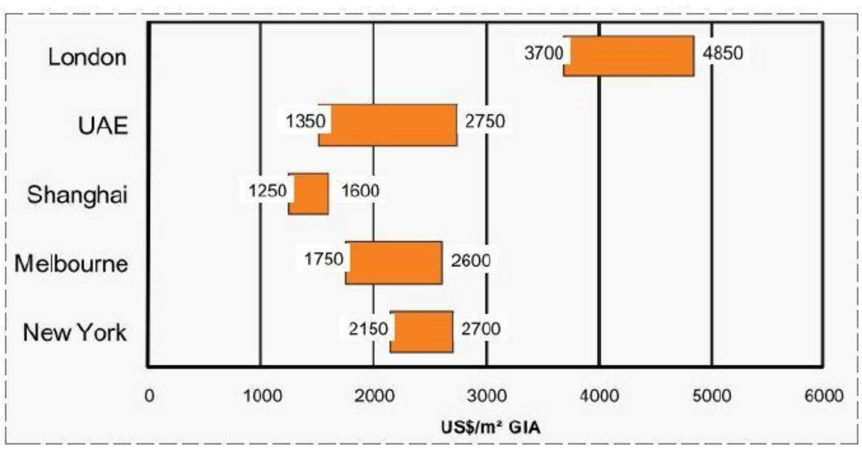


Figure 19 – Shell and Core High-rise Construction Cost Range (USD/sqm GIA) (source: (Watts & Langdon 2010)**)**

A 2009 research (Oldfield et al. 2009) with outstanding complexity is aiming to create a new typology of tall buildings according to their energy use. The authors provide a thorough historical analysis of tall buildings in several aspects influencing their energy use, such as building form, façade construction, attitude to natural lighting, ventilation strategies, etc. As a conclusion of the research, tall buildings are categorized into five energy generations, depending on their energy consumption characteristics:

- The first category embraces early skyscrapers built before the 1916 New York Zoning Law, consisting of compact shapes, high levels of façade thermal mass, low façade transparency and average surface/volume (A/V) ratio of 0.107;
- The second category ranges from the Zoning Law to the 1951 development of glazed curtain wall, incorporating buildings with slender shape, high façade thermal mass, low façade transparency, more common use of air conditioning and average A/V ratio of 0.152;
- The third category is ranging between the development of glazed curtain wall and the 1973 energy crysis, featuring buildings with compact shape, single-glazed curtain wall systems, high façade transparency, reliance on mechanical conditioning and fluorescent lighting and average A/V of 0.111;
- The fourth category ranges from the 1973 energy crysis and to present day, gathering buildings with compact shape, double-glazed curtain walls, high façade-transparency, reliance on mechanical conditioning and average A/V of 0.088;
- Finally, the fifth category is embracing skyscrapers from the 1997 rise of environmental consciousness to present day, featuring buildings with slender shape, high performance double-skin and triple-glazed curtain walls, high façade transparency, exploited natural ventilation possibilities, on-site energy generation and average A/V of 0.146. (see Figure 20 for details)

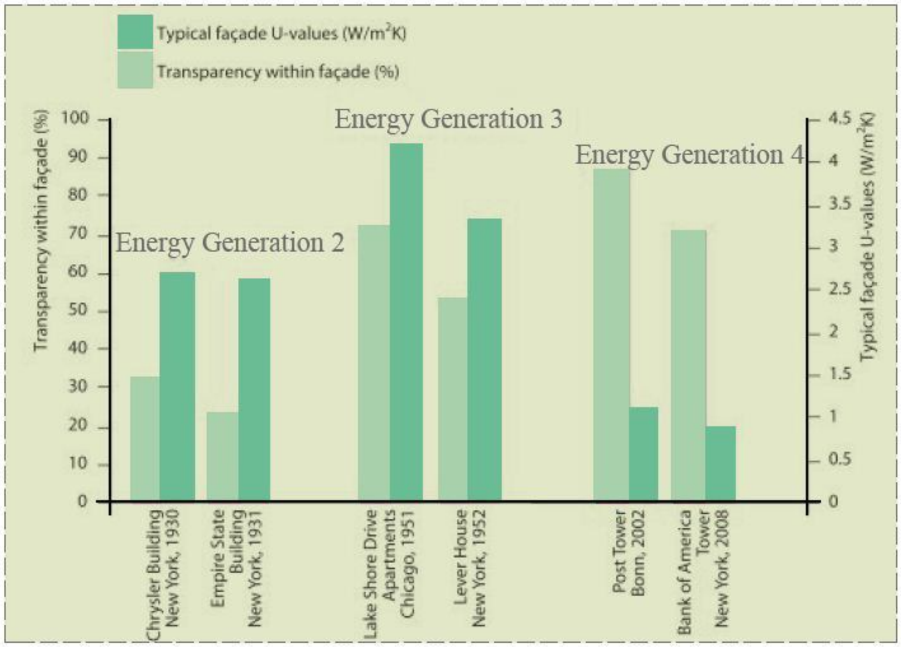


Figure 20 – Comparison of different energy generations (edited by author, source: (Oldfield et al. 2009)**)**

1.5.Trends of today

Some of the main trends of global tall building construction are to be pointed out below in order to give a context to other discussed topics of the present study.

Along with the global population and economy growth, the phenomenon of urbanization is continous, especially in less developed countries. According to a 2008 conference proceeding, more than 50% of the world's population was living in cities by 2007, while it is above 70% for Europe, Americas, Japan and Australia(UNEP-SBCI - Sustainable Buildings & Climate Initiative) 2009). As global economy, population and cities grow; the number and height of tall building constructions show a strong and stable uptrend(CTBUH 2013a); however the market has witnessed a few downturns, particularly during WWI and II, the Great Depression and the '73 Oil Crisis(Hollister et al. 2011). By 2020, it is projected that as many as 8 skyscrapers are going to surpass the "megatall" height criteria; all of them to be constructed in Asia(CTBUH 2011).

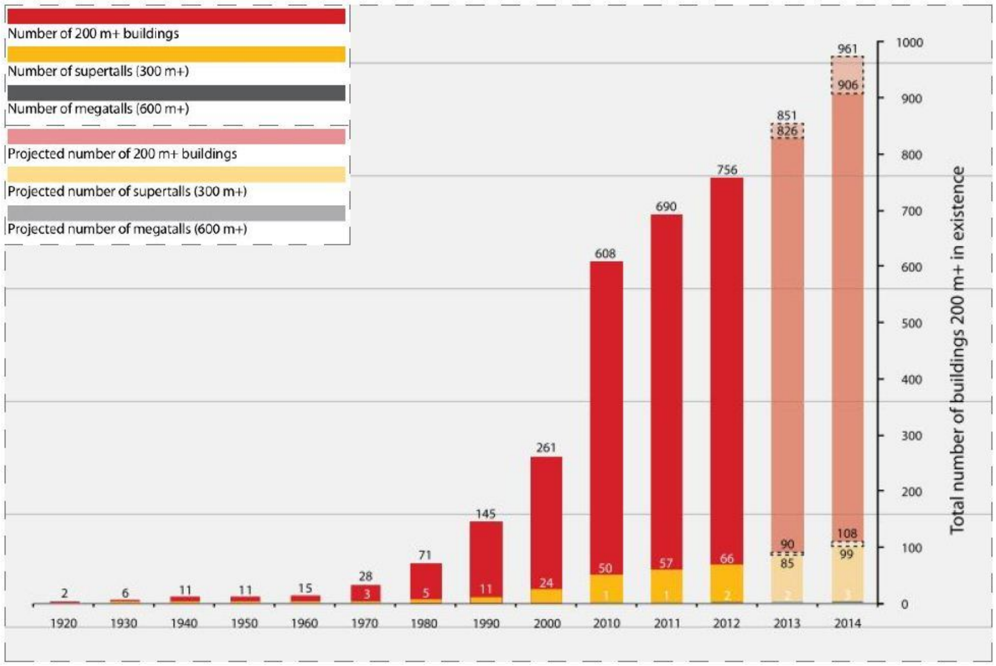


Figure 21 – Tall buildings - number and height trends (edited by author, source: (CTBUH 2013a)**)**

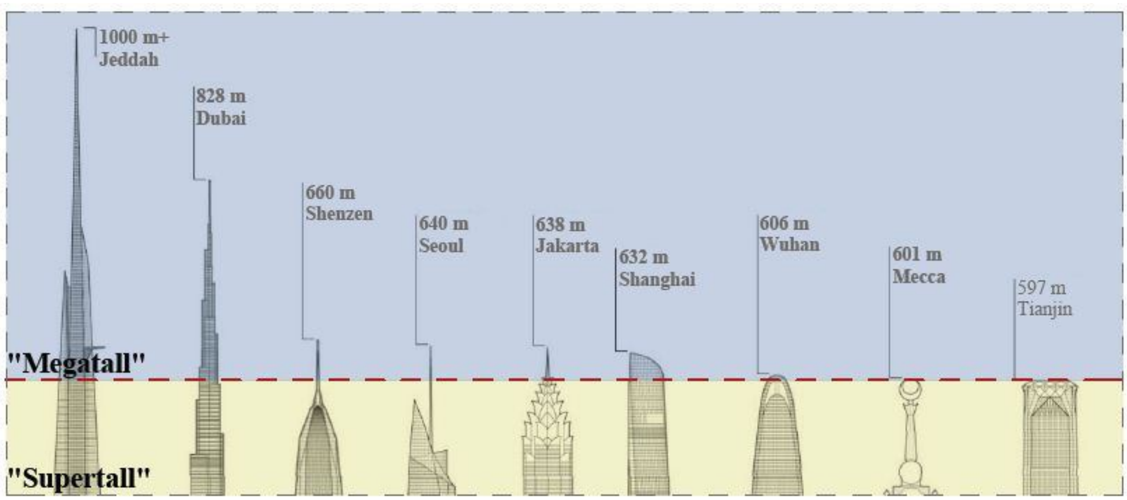


Figure 22 – Megatall buildings completed by 2020 – (edited by author, picture source: (CTBUH 2011)**)**

Based on the past five years' (2008-2012) journal reports from the Councin on Tall Buildings and Urban Habitat (CTBUH n.d.), the following statistical results could be drawn[2]:

- 315 buildings over 200 meters architectural height were completed globally in the past five years (2008-2012); this is 235% of the number from five years before (2003-2007);

[2] *Statistics deal only with buildings over an architectural height of 200 meters

- More than 50% were completed in Asia, 25% in the Middle East, while Europe, the Americas and Australia is sharing 20%;
- Concrete's share is 70% as the main structural material, with 20% for Composite and less than 10% for Steel and Mixed;
- As a new tendency of the period, Residential buildings – with almost 37% share - slightly overtook those with Office function (33%); leaving 24% for Mixed use buildings and less than 6% for Hotels, while Education appeared as a tall building function represented by one building.(Figure 23 – Statistisc of the previous five years (figure by author, data source: **(CTBUH n.d.)**)Figure 23)

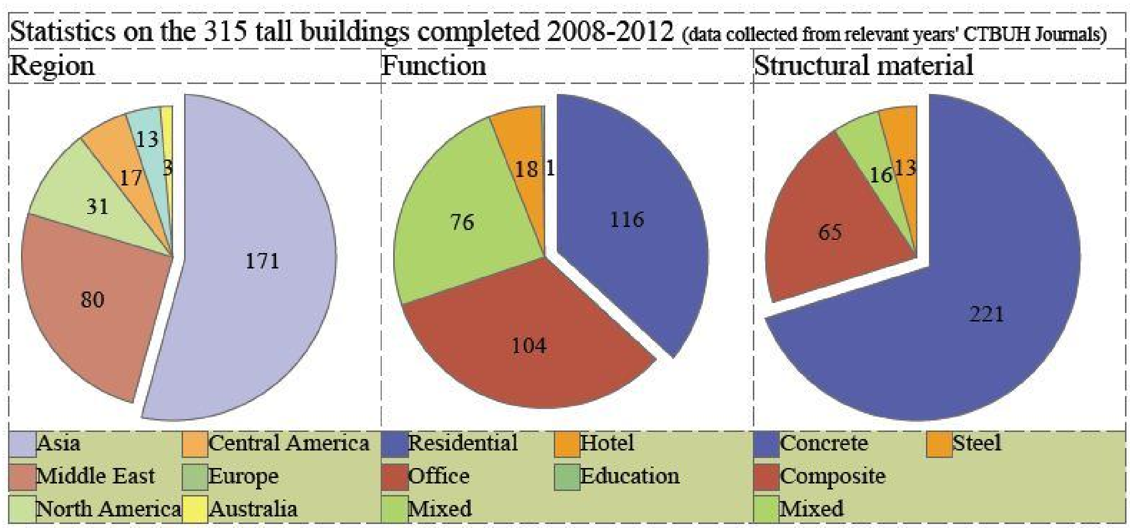


Figure 23 – Statistisc of the previous five years (figure by author, data source: (CTBUH n.d.)**)**

1.6. Economical considerations

As previously indicated in Chapter 1.2.; one of the main drivers leading to the birth of skyscrapers was economical. One can assume that vast majority of tall building projects serve speculative purposes. Cass Gilbert, a prominent American architect from the age of the early skyscrapers calls this building type "a machine that makes the land pay"(Gilbert 1900).

Tall buildings require a considerably greater amount of financial investment compared to low-rise buildings, which is a result of differencies in many variables, such as structural system, mechanical systems, vertical transportation, etc. Based on data from Central London, average extra investment is as much as 37% (Watts & Langdon 2010). However the investment is also great in terms of time and human capital; therefore appropriately exploring a project's feasibility is with great importance (Al-Kodmany & Ali 2013, pp. 47). Feasibility studies also indicate a so called "economic building height", which is practically the optimal number of storeys in order to reach the best return rate from rent. In spite of being aware of the economical "top limit" of height; investors happen to surpass it for their own reason – which is often their idea of going taller than the neighbours. This attitude is nothing new – if one would think of today's "about-to-be-built" megatall buildings -; it has been the same a century ago with buildings like Singer Building, Chrysler Building or the Empire State Building (Al-Kodmany & Ali 2013, pp. 48-49)(Dolkart 2013).

As previously revealed, there is a grand difference in average specific tall buildings' construction cost according to the project's geographical location. This breaks down to differences in raw material and product prices, general labour costs, and also different amount of relative investment on certain building parts. For example, more than 30% of a typical Shanghai tall office building's construction cost goes for the superstructure, while it is just slightly more than 20% in the UAE or London. At the end of the day, average construction cost/GIA is still less than half in Shanghai than in case of the other two locations. A recent study – however - is revealing the possibility of constructing a state of the art low energy tall London office building for less than 60% the cost of the statistical average(Watts & Kimpian 2012).

The Life Cycle Cost (LCC) of a building is also very dependent on the geographical location and building function; moreover there could be considerable correlation with building height(Roaf et al. 2009, pp. 243-244). There is no material published providing statistical data on the ratio between tall buildings' construction costs and life cycle cost; however it would possibly reveal great amount of money saving potential, helping to drive general attitude towards cost-effective and energy-conscious design alternatives.

While one can see that firms of global recognition are inching towards the solution (see, (Watts & Kimpian 2012; Partridge 2012)), the following words probably remain truth:

"While the topics of energy use, environmental performance,

life-cycle costs, and integrated design have each been studied, no study combines all aspects together to determine the simultaneous impacts of energy efficient design on life-cycle costs, life-cycle carbon emissions, and energy use in an integrated building design context for commercial buildings across different climate zones." (Kneifel 2010)

2. Sustainability

2.1.Initial thoughts

The concept of sustainable development is constantly developing and gaining more attention since it was first defined in 1987. Nations, organizations, companies and individuals across the globe interpreted „sustainable” for the context of their interest, which also led to general uncertainities and confusion. UNEP addressed a great measure of environmental responsibility to the building industry, further strenghtening the significance associated to „sustainable building” or „sustainable architecture”.

Green building movement emerged independently from the concept of sustainable development (Berardi 2013), however its concept rests upon common values, even though green building involves a narrower field of understanding. The terms green and sustainable are often falsely comprehended or interchanged (Nguyen & Altan 2011; BSC 2008; Berardi 2013; Korkmaz et al. 2009), which is making a significant contribution to the already confused atmosphere. There are numerous aims to create appropriate evaluation criteria and rating tools for both green building and sustainable building(Bauer et al. 2010, p.15), however appropriate evaluation is only possible along clear understanding of terminology. The present chapter intends to clarify the meaning and give an understanding on „sustainable building” in the context of sustainable development, terminology, principles and rating systems, based on available literature.

2.2.Sustainable development

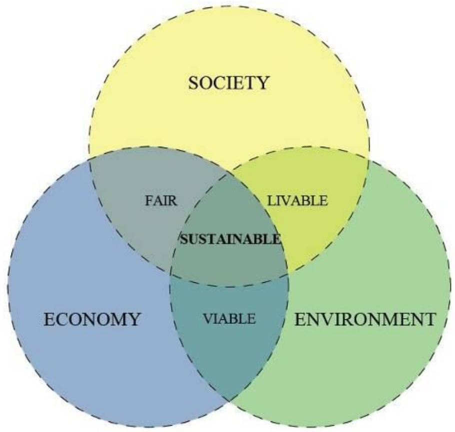


Figure 24 - Common graphical interpretation of the sustainable development concept (figure by author)

2.2.1. Birth and understanding

Sustainable development was first defined and globally published in the World Commission on Environment and Development (WCED)'s 1987 report: „Our Common Future". The so called „Brundtland Report" revealed numerous acute problems and global trends in terms of environment, economy and society; such as food shortage, drylands' desertification, deforestation or global warming (WCED (World Commission on Environment and Development) 1987, pp.16–20). The Report aimed to change the „quality of growth" by declaring that environmental issues are inseparable from economic development (WCED (World Commission on Environment and Development) 1987, p.12). The new order would this way harmonize with the broadest sense of sustainable development: to „promote harmony among human beings and between humanity and nature" (United Nations 1987, pp. 50).

The most cited – and probably the most generic – definition is also coming from the Report: *„Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*(WCED (World Commission on Environment and Development) 1987, p.37).

There are – however – very important further statements in the same report, some of which are necessary to be aware of in order to understand the context of today's issues about sustainable development:

- First, *“the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given”*(WCED (World Commission on Environment and Development) 1987, p.37)*;*
- *Second, „the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs”*(WCED (World Commission on Environment and Development) 1987, p.37)*;*
- *Third, “sustainable development is not a fixed state of harmony, but rather a process of change”*(WCED (World Commission on Environment and Development) 1987, p.15);
- Finally, *“the goals of … development must be defined in terms of sustainability in all countries … Interpretations will vary, but must share certain general features and must flow from a consensus on the basic concept of sustainable development”*(WCED (World Commission on Environment and Development) 1987, p.37).

Gro Harlem Brundtland’s Commission probably served as a catalyst to many events with global importance in terms of sustainability - such as the 1995 commence of WTO, the Agenda21 actions or the 1997 signing of Kyoto protocol. Unarguably Brundtland Report is one of the most influential international political statements for the 21st century. (For further information see: Table 1; Figure 25 – Subjective timeline related to sustainable development (figure by author)

Table 1 – Comparison of social, economic and environmental sustainability – (table by author, based on (Goodland 1995)**)**

Social Sustainability	Economic Sustainability	Environmental Sustainability
social capital cohesion of community, cultural identitiy, diversity, sodality, comity, tolreance, humility, compassion, patience, fellowship, fraternity, love, prulalism common standards of law, honesty, discipline moral capital shared values equal rights community, religious and cultural interaction human capital education health nutrition	stable economic capital ebracing natural, social and human capital "people and irreversibles are at stake, economics needs to use anticipation and the precautionary principle routinely and should err on the side of caution in the face of uncertainity and risk"	"the maintenence of natural capital" protection of raw material sources holding the scale of human economic subsystem to within the biophysical limits of the overall ecosystem on which it depends holding waste emissions within the assimilative capacity of the environment harvest rates of renewables must be kept within regeneration rates holding non-renewable depletion rates equal to the rate at which renewable substitutes can be created

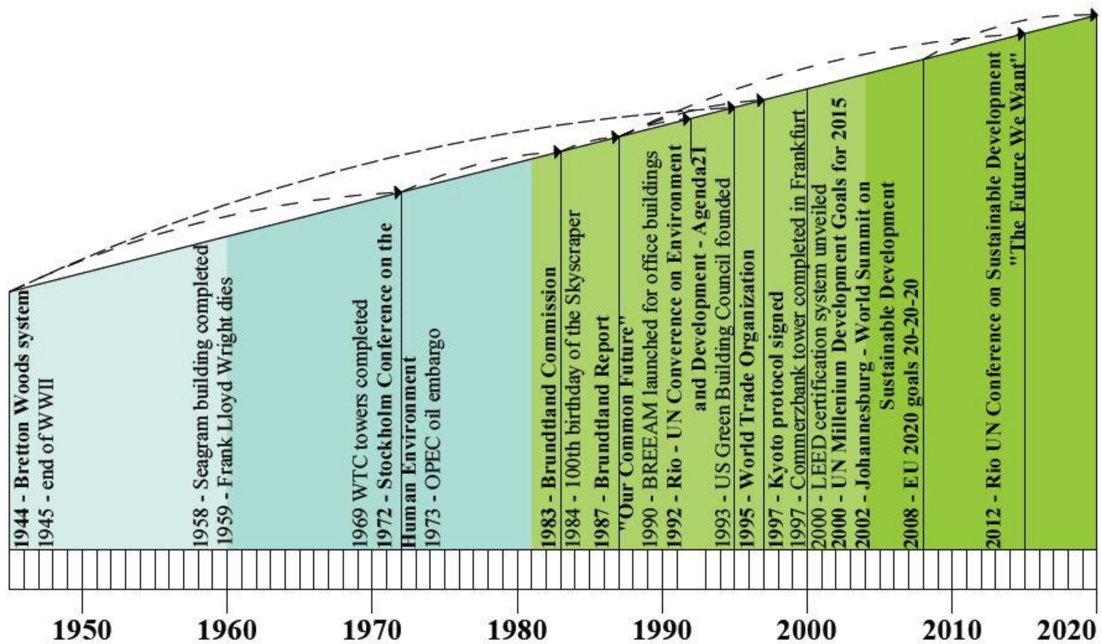


Figure 25 – Subjective timeline related to sustainable development (figure by author)

2.2.2. Controversy

As cited in 2.2.1., "Our Common Future" already indicated certain preculiarities about sustainable development's relativeness to time and space. The present chapter is addressing the controversy most likely caused by these preculiarities.

According to the Brudntland Report(1987, pp. 15), "sustainable development is not a fixed state of harmony, but rather a process of change". Not surprisingly, it has been adaped and reinterpreted across the globe, resulting in at least a hundred different definitions (Hopwood et al. 2005, pp. 38-52).

Grosskurth and Rotmans (2005) revealed that existing interpretations are time dependent, include several levels of scale and space, multiple dimensions and social dependencies. Along these four logical lines, Berardi (2013) aims to review the debate on today's interpretation of sustainable development.(Table 2)

Table 2 – Outlines of today's controversy about interpreting sustainable development (table by author, based on (Berardi 2013)**)**

Time dependence	Spatial dependence	Dimensional dependence	Social dependence
the farther we go into future, the less accurately we can predict adaptive flexibility required according to the available knowledge at any given time	locally specific and more a matter of local interpretation than a universal goal requires continous evaluation at several scale levels	sustainability is often evaluated considering only one dimension there is a pressure to add political and cultural dimensions to the currently used ones (environmental, social and economical)	participation of people is inevitable different people with different interpretations results in more uncertainity

One can see that sustainable development is a constantly changing ideal of synthesis between human beings and nature, resting upon the complex interaction of many variables, such as space, time or society. Accurately and dynamically addressing the relevant dimensions of sustainability on every level of our "growth" remains a great challenge. This accuracy – at the end of the day – is going to justify or deny human existence in the long run.

2.3.Sustainable building

2.3.1. Importance

As stated in 2.1., built environment is directly or indirectly responsible for a considerable portion of environmental disorders revealed by the Brundtland Report. In fact, building sector contributes to 30% of global green house gas (GHG) emissions and consumes up to 40% of primary energy annually(UNEP-SBCI 2009). In 2015, approximately 50% of then existing Chinese building stock is going to be younger than 15 years(UNEP 2003, p.5). In case of a do-nothing scenario, buildings' GHG emissions would double in the next 20 years (UNEP-SBCI 2009). GHG emissions are directly associated with global warming, thus several harmful global trends, such as ocean warming, Arctic ice sheets melting, increasing sea levels or ocean acidification(IPCC-WGI 2013, pp.3–19). At the same time, the level of GHG emissions from buildings is closely correlated to their energy demand, supply and source(UNEP-SBCI 2009). The previous facts give a good context for one to understand, that "buildings offer enormous scope for energy savings, and perhaps the most widely understood ways of increasing energy efficiency are in the home and workplace."(WCED(World Commission on Environment and Development) 1987, p.137).

2.3.2. Sustainable building as a process of change

As previously discussed, constant *change or evolution* is a very significant factor in the nature of sustainable building. Accordingly, it is important to maintain a cycle on everly level of action performed, which includes feedback, allowing constant adjustment. A subjective figure is presented to describe a desirable flow of change in order to ensure the right way of evolution. (Figure 26)

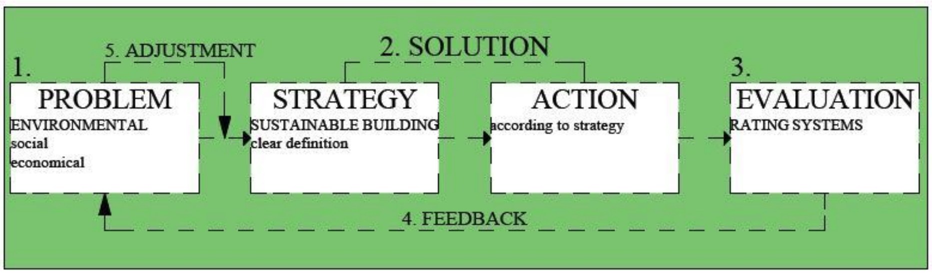


Figure 26 – The cycle of change in sustainable building (figure by author)

2.3.3. In search of a definition

As "Sustainable Building" is supposed to interpret the concept of "Sustainable Development" on the level of built environment, hence the resulting definition is arguably to have certain characteristics by its nature, such as:

1. Addresses environmental, social and economic domains;
2. Being relative in terms of time, space and community.

Partially because of the definition's relative nature, Kemp (2010) states that technology can not be labeled sustainable, which could actually indicate that using the term for buildings don't make sense either(Berardi 2013, p.76).

Berardi addresses difficulties in defining sustainable building to the same logical dependencies we discussed before in (2.2.2.)(Berardi 2013, pp.74–76). According to a recent article of him, multi-scale impacts, multi-domain criteria and the need for long term cradle-to-cradle evaluations drive sustainable building to a new understanding; in which [sustainable buildings] are not simple consumers but active part of the environment, and are designed to help its regeneration(Berardi 2013, p.74). He also states that recent emergence of new principles and requirements for sustainable building indicate the commence of a new common vision of sustainable building(Berardi 2013, p.76). Finally –

based on a thorough review of today's interpretations and trends - he provides a new definition to sustainable building, which is as follows:

A sustainable building is *"a healthy facility designed and built in a cradle-to-grave resource-efficient manner, using ecological principles, social equity, and life-cycle quality, and which promotes a sense of sustainable community. According to this, a sustainable building should increase:*

• *demand for safe building, flexibility, market and economic value;*

• *neutralization of environmental impacts by including its context and its regeneration;*

• *human well being, occupants' satisfaction and stakeholders' rights;*

• *social equity, aesthetics improvements, and preservation of cultural values."*(Berardi 2013, p.76)

2.3.4. Green or Sustainable

According to Kibert (2012), the idea of environmentally responsible buildings is rooting in the mid 20th century. Others agree (Korkmaz et al. 2009), that green building movement started in 1962, and served as a catalyzator for events like the First Earth Day in 1970. One of today's biggest advocate of green building is unarguably the US. Green Building Council, which was established 1993(USGBC 2013).

EPA (2008) defines green building „as the practice of maximizing the efficiency with which buildings and their sites use resources—energy, water, and materials—while minimizing building impacts on human health and the environment, throughout the complete building life cycle—from siting, design, and construction to operation, renovation, and reuse."

According to Booz Allen (2009), McGraw Hill defines green building as „one built to LEED standards, an equivalent green building certification program, or one that incorporates numerous green building elements across five category areas: energy efficiency, water efficiency, resource efficiency, responsible site management and improved indoor air quality. Projects that only feature a few green building products (e.g., HVAC systems, waterless urinals) or that only address one aspect of a green building, such as energy efficiency, are not included in this calculation.".

The Office of the Federal Environmental Executive (2002) defines green building "as the practice of (1) increasing the efficiency with which buildings and their sites use energy, water, and materials, and (2) reducing building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and removal—the complete building life cycle.”

All of the above definitions address buildings’ energy efficiency, water use and materials. Two of them also highlight buildings’ general impact on environment and human health, and the need for a life-cycle approach.

Table 3 – Contrasting Green building and Sustainable building (adopted from: (Berardi 2013; based on UNEP 2003)**)**

Major issues of the building performances	Green building	Sustainable building
Consumption of non-renewable resources	x	x
Water consumption	x	x
Materials consumption	x	x
Land use	x	x
Impacts on site ecology	x	x
Urban and planning issues	(x)	x
Greenhouse gas emissions	x	x
Solid waste and liquid effluents	x	x
Indoor well-being: air quality, lighting, acoustics	(x)	x
Longevity, adaptability, flexibility		x
Operations and maintenance		x
Facilities management		x
Social issues (access, education, inclusion, cohesion)		x
Economic considerations		x
Cultural perception and inspiration		x

The problem of interchanging words “green” and “sustainable” was revealed before in chapter 2.1. One can possibly agree that sustainable building asks for more than minimizing environmental impact(Berardi 2013) by adding economical and social requirements to the criteria.(Table 3) Following this logic, there must be a strict distinction in the use of the terms, although there is a strong connection between them as green building could arguably be defined as the environmental leg, a contributing element of sustainable building. (Figure 27)

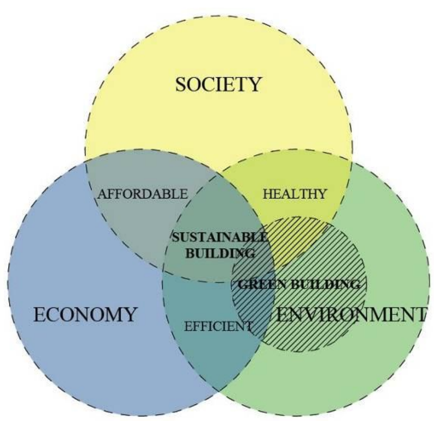


Figure 27 – Hierarchy between green building and sustainable building – author’s interpretation

3. Sustainable tall buildings

3.1.Initial thoughts

The paper has so far discussed two major topics: tall buildings and sustainability. Former chapters indicated that construction of tall buildings show a global uptrend, while sustainability is becoming an inevitable quality for new buildings.

As a further step, the present chapter is aiming to investigate whether tall buildings could be considered as a sustainable typology or not. The evaluation process is as follows:

1. Arguments „for” and „against” are summarized merely from today’s available literature on the topic;
2. As a method for assessing the viability of the concept, arguments are organized into a SWOT matrix;
3. Based on the SWOT matrix, conclusions are drawn.

3.2.„For” and „Against”: the major aspects

Few would argue that tall buildings are a very unique building type, as they have a great general impact in terms of society, environment, economy, infrastructure, etc. On one had they are “proud and soaring things”(Sullivan 1896) symbolizing cutting edge technology and human power; still on the other hand they remain of the most controversial things ever created in terms of public opinion.

Processing today’s available literature on tall building sustainability, one can identify distinctive general characteristics of the arguments. First, they can be divided to three groups according to which dimension of sustainability they address. Second, across the three dimensions of sustainability, they can be associated to several major topics, such as urban density, building height, cost, energy consumption or symbolism. The present chapter is aiming to provide an overview of the several major topics identified.

3.2.1. Symbolic nature

For many people, tall building is associated with the negative sense of human ego(Roaf et al. 2009), the selfish, stubborn ego, which is dwarfing its neighbours and most of the street-level activities(Domosh 1987). Others remember the numerous fails of high-rise building projects, where the lack of planning, effort and quality resulted in unacceptable living conditions(Al-Kodmany & Ali 2013). However, if associated with the positive sense of human ego, the ever-active, aspirative and inventive ego, tall buildings serve as a symbol of human development and serve as a cohesive power for society by making people proud (Al-Kodmany & Ali 2013). How could we imagine today's big cities without skyscrapers?

Closely related to sustainability, tall buildings carry a huge potential in serving as "green totems", which are moving public communication forward in the field of sustainable development(Murray 2012); however there is a big danger of "greenwashing" generating distrust towards tall building sustainability(by Scott in,Keating et al. 2012).

3.2.2. Urban density

Dense high-rise environments often suffer of overcrowdedness, increased demand on transportation, infrastructure, power grids and sewing system(Roaf et al. 2009)(Collins et al. 2008). Moreover, dense tall neighbourhoods significantly contribute to head island effect(Roaf et al. 2009), which is certainly unsustainable. In spite of the high density, many tall buildings are leaving empty plazas around them and create isolation by the way they meet the ground(Goettsch 2012)(Koolhaas 2008). Luckily, there are many examples for the opposite as well, such as OMA's CCTV Building in Bejing, the Leadenhall Building in London or the Hong Kong International Commerce Centre by Kohn Pedersen Fox.

However, the world's population keeps growing and heavy urbanization is part of the development process(Niu 2004; WCED 1987). Tall buildings are certainly a solution to help cities in their quest to accommodate all the newcomers. Despite all the problems and challenges, urban density has many positive effects too. Dense cities and mixed use tall environment are greatly reducing time spent with traveling; such agglomerations create better dispersion of innovative activity, and in general add value and vitality to cities(Wood 2008; Al-Kodmany & Ali 2013). Moreover, shorter travel times and distances in dense neighbourhoods greatly contribute to a city's energy consumption, thus sustainable performance(Figure 28); having not mentioned the contribution to preserving natural open spaces by reducing land consumption(Wood 2007; Al-Kodmany & Ali 2013).

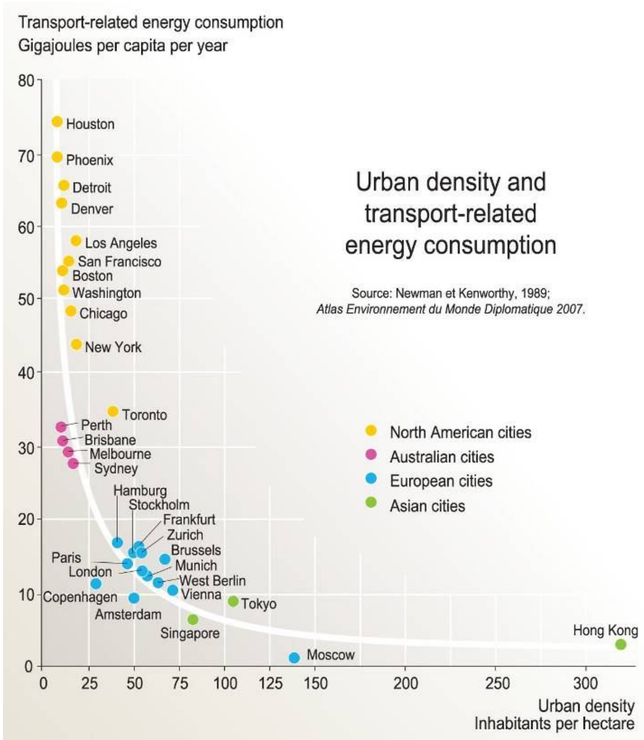


Figure 28 – Urban density and transport-related energy consumption (Source: UNEP)

3.2.3. Height

Living or working high is addressed with causing several – mainly social – problems; such as one living up high losing contact with nature and society, resulting in poor health and productivity loss; while comfort and security is constantly dependent on technology, like air conditioning or elevators(Wener & Carmalt 2006). However, a distinctive amount of people (Yeang 2008; Wood 2008; Wener & Carmalt 2006; Collins et al. 2008; Ali & Armstrong 2010) see a very good opportunity in tall buildings to restore the contact with natural elements, such as light, air or vegetation. In fact, WHOA is “selling” their tall residential skyscrapersin Bangkok by promoting the advantages of height; namely the less noise, better air quality, good daylighting and nice views.

3.2.4. Energy and carbon

Probably one of the most intense fields of debate is the energy consumed and potentially saved, and the carbon embodied and emitted over the life cycle of tall buildings. This is a very komplex topic driven by many variables.

Tall buildings considerably more energy and embodied carbon for their construction and operation than low-rise buildings(Trabucco 2011; Oldfield 2012; Yeang 2008). Oldfield (2012) states that there is a great potential for reducing embodied carbon by employing structural optimization, passive design strategies or using recycled materials in place of virgin ones. (Figure 29) Recent tall building projects, such as the Bank of America Tower in Manhattan, the Pearl River Tower in Guangzhou or the ANZ Bank Center in Sidney could demonstrate that energy efficient new skyscrapers can reduce their energy use by at least 50%(Frechette & Gilchrist 2008)(Partridge 2012). Ken Yeang confirms that some of his bioclimatic skyscrapers consume as much as 30% less energy than the Singaporean standard office building(Davies 1999).

There are many opportunities especially for tall buildings to save and produce energy because of their height(Leung & Weismantle 2010), such as decreasing their cooling demand by the decreasing temperature, harnessing wind and solar power, using pressure differences to help ventilation or creating vertical pressure zones for their mechanical systems(Mehdi in,Keating et al. 2012; Leung & Weismantle 2010).

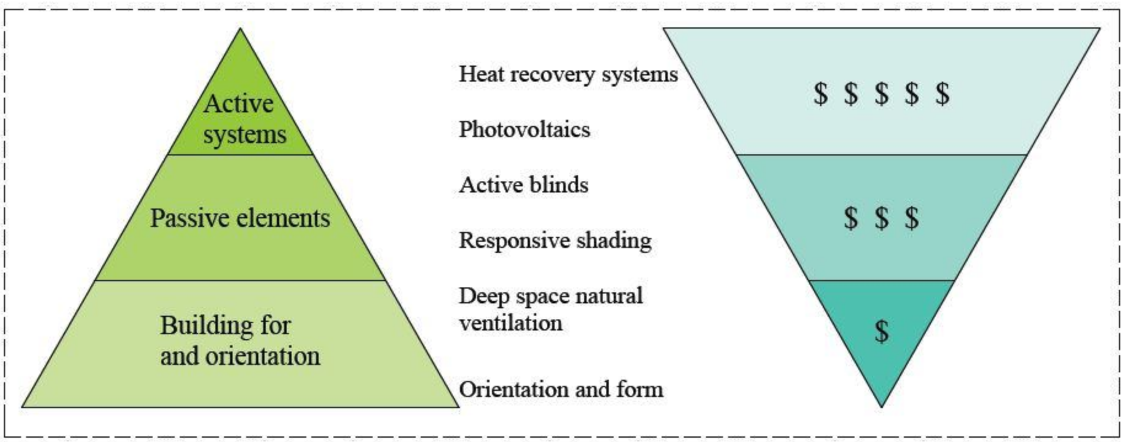


Figure 29 – What makes a building green? (Figure by author, source: ARUP)

3.2.5. Cost

The topic has previously been addressed in chapter [0]; however there are further things to discuss. Both Mehdi and Keating (2012) states that one of the major barriers of sustainable tall buildings is their cost. According to Taranath, above 50 storeys, extra cost for lateral bracing ranges from 7 to 10% of overall construction costs(Taranath 2010, p.697). Moreover, the relative available floorspace is about 10% less than in case of low-rise, merely because of the core and the vertical transportation sytem(Al-Kodmany & Ali 2013). Employing green strategies are just "making it worse" when it comes to tall building projects, as tall already costs around 30% more than low-rise buildings(Yeang 2008; Watts & Langdon 2010). However a previously discussed study (Watts & Kimpian 2012) presents a case study for a state-of-the-art London office buiding with shell and core construction costs reduced as much as 40%. According to the USGBC, achieving LEED Platinum brings an additionall cost between 2-12.5%(World Green Building Council 2013). However with height, not only costs are more, but the economic premium for renting and selling as well, since tall is attractive, however more research is needed in this area.

USGBC (2013) also states that in contrast with the extra cost, LEED Platinum brings more tenants, enchances workplace productivity and decreases building energy use by 35-40%.

If LEED – for green building – increases value, investing further money into sustainability aspects would probably do the same; however sustainability labels – in contrast with green building labels - today are non-existant.

3.2.6. Preservation

Preserving our historical cities and sights are becoming more and more important, for example London – smartly - introduced “Landmark Viewing Corridors” ranging across the city in order to protect sights from built objects(Murray 2013). Tall buildings undoubtedly have a great responsibiligy in preserving historical sites and views for cities around the world. Unfortunately many cases show that the western “refrigerator box” concept of tall building has been exported to everywhere in the world, primarily to Asia, where constructing buildings like that in old cities caused much harm(Wood 2008). If tall buildings can act as a “good totem” – as discussed before – this way they do the opposide. Fortunately, there are cases when much attention is paid (or has to be paid) on preserving views and historical sites(Tavernor 2007), such as the Leadenhall Building’s case in London, which was shaped in order to preserve the view to the St. Paul’s Cathedral (Figure 30 – Visual sustainability?. Should this be then called visual sustainability?

Figure 6. Leadenhall tapering silhouette responding to the viewpoint to the St. Paul's Cathedral. © RSH+P

Figure 30 – Visual sustainability? (Adopted from: (Young et al. 2013)**)**

3.3. SWOT analysis

3.3.1. Strenghts

STRENGHTS
SYMBOLISM – representing human development; "proud and soaring"; makes central life attractive for urban regeneration; serving as icon for identifying cities; symbols of progress in global competition between cities **DENSITY** – reduced suburban spread; reduced travel time = reduced wasted time; greater geographic concentration = more innovative activity; adds value and vitality to cities; mass transit creates sustainable cities **HEIGHT** - increased access to views, light, less noise and pollution **CATALYZATION** – encourage research in many fields, such as structural systems, building services, facades, materials, etc.; they increase value of surrounding properties **ENERGY** – reduced travel time = reduced fuel consumption; good surface-to-volume ratios in terms of energy efficiency; shorter power lines = decreased energy losses; many potential energy saving strategies are resting upon building height; high potential for demonstrative energy efficient projects, such as Pearl River Tower(Guangzhou), Bank of America Tower(New York), ANZ Bank Center(Sydney) **ECOLOGY** – efficient land use = preserving natural open spaces; reduced travel time = reduced GHG emissions; very long life cycle for superstructures = CO2 conservation; **COST** – highly efficient use of a land area, "a machine that makes land pay"; demonstrative projects show that it is not necessarily more expensive
Based on arguments summarized from: (Roaf et al. 2009; Wood 2008; Wood 2007; Ali & Armstrong 2010; Al-Kodmany & Ali 2013; Collins et al. 2008; Trabucco 2011; Frechette & Gilchrist 2008; Leung & Weismantle 2010; Yeang 2008; Watts & Kimpian 2012; Tavernor 2007; Murray 2012; Murray 2013; Oldfield et al. 2009; Wener & Carmalt 2006; Koolhaas 2008; Keating et al. 2012)

3.3.2. Weaknesses

WEAKNESSES
SYMBOLISM – tall typology mostly failed to renew itself in an urban context = closed glass boxes with empty plazas around; many “one size fits all” glass “refrigerator” boxes exported worldwide; many unattractive and lacks quality; often anti-social internal environment, lack of open-, recreational- and common spaces **DENSITY** – switching life-sytle change from low- to high-rise is not suitable for first generation; increased crowdedness; increased demand on transportation and infrastructure, such as power grids, sewing systems **HEIGHT** – isolation from nature is effecting health and productivity in a negative way, some people suffer from vertigo; overshadowing; high dependence on technology in terms of comfort and safety; greater wind loading at higher altitude **ENERGY** – generally lower area-to-volume ratio = less space for harnessing solar energy; low feedback about designed and actual building energy performance, lack of availavle data; higher energy consumption because of mechanical systems and elevators; **ECOLOGY** – up to 58% higher embodied carbon/GFA compared to UK low-rise dwellings; urban heat-island effect; relatively more structural material demand; often sealed environments at heigh depending on air conditioning and natural lighting **COST** – up to one third premium to construct; usually iconic designs add to cost; approximately 10% less relative usable area to floors; high maintenance cost, since mechanical systems, elevators running, etc.
Based on arguments summarized from: (Roaf et al. 2009; Wood 2008; Wood 2007; Ali & Armstrong 2010; Al-Kodmany & Ali 2013; Collins et al. 2008; Trabucco 2011; Frechette & Gilchrist 2008; Leung & Weismantle 2010; Yeang 2008; Watts & Kimpian 2012; Tavernor 2007; Murray 2012; Murray 2013; Oldfield et al. 2009; Wener & Carmalt 2006; Koolhaas 2008; Keating et al. 2012)

3.3.3. Opportunities

OPPORTUNITIES
SYMBOLISM – tall buildings as symbols of sustainability, moving public discussion forward, provide social cohesion and a sense of community **DENSITY** – tall buildings as solution for global global population growth paired with urnabization; tall and sustainable as further development direction for metropolises **PLACE MAKING** – interconnected functions and spaces, which are available for public use; new functions, such as sport or agriculture; creating functional and spatial variety with height; potential for secure communal/recreational spaces in the sky, away from traffic and pollution **ENERGY** – intelligent, user-friendly control for systems = high energy saving potential; home and workplace proximity = further reduced travel time, more productivity; high wind velocities = potential in harnessing wind energy; higher potential in harnessing solar energy in heights (lower temperatures, less pollution, less overshading); higher atria volumes = higher potential in stack effect; lower air density, temperature and moisture content in heights = 1) significant ventilation energy saving and 2) passive cooling potential; vertical variation of envelope **ECOLOGY** – tall buildings = big air filters in the city; collecting, storing, disinfecting and reusing rainwater = less impact on sewing systems; vertical greenery and vegetation = decreasing urban heat island effect; occupants control of their environment; restoring contact with natural elements by vegetation, sky gardens, natural air and light; natural lighting advantage in heigts; recycled materials/cement substitutions = high CO_2 saving potential **COST – SAVING:** structural optimization; standardized use of materials; simle and repetitive construction; precast elements; modular construction; prefabrication; **ADDING VALUE:** highly energy-saving buildings; cheap and easy maintenance; healthy work environment; increased productivity; **EDUCATION** – educating tenants, residents for an environmentally conscious way of using buildings; users meet the numbers of performance and learn how to influence them; phase: “how little do we need?” **RESEARCH & DEVELOPMENT** – new, stronger, lighter materials likely to be available; technology transfer from aircraft industry;
Based on arguments summarized from: (Roaf et al. 2009; Wood 2008; Wood 2007; Ali & Armstrong 2010; Al-Kodmany & Ali 2013; Collins et al. 2008; Trabucco 2011; Frechette & Gilchrist 2008; Leung & Weismantle 2010; Yeang 2008; Watts & Kimpian 2012; Tavernor 2007; Murray 2012; Murray 2013; Oldfield et al. 2009; Wener & Carmalt 2006; Koolhaas 2008; Keating et al. 2012)

3.3.4. Threats

THREATS
SYMBOLISM – failing future tall building projects = symbol of a failing idea; symbols of greenwashing and sustainable ornament; **DENSITY** – overpopulation, unrealisticly high demand on infrastructure and power grids = shortages; dense, tall neighbourhoods are easy target for terrorist attacks **COMMUNICATION** – developers neglecting public communication can lead to public denial **PRESERVATION** – ad hoc constructions can destroy historical site views, can harm sites of heritage, etc.; further globalization of "one-size-fits-all" western style box = destroying cultural identity **LEGISLATION** – lack of standardization, uncoordinated legislation, insufficient incentives to developers, high level of burocracy, existing landmines in building codes **ENERGY** – lack of demand, lack of available data, lack of industry feedback about energy performance; gap between designed and actual energy consumptions; **COST-** falsely estimated economic cycles could cause bankrupted, upheld tall building projects; lack of tenant interest in sustainability **ECOLOGY** – greenwashing and sustainable ornament (sustainable towers in Dubai); infrastructural, technology problems of maintaining a zero impact life cycle; efficient buildings leading to high embodied carbon **ASSESSMENT** – no currently available comprehensive sustainability assessment tool designed for tall buildings on the market
Based on arguments summarized from: (Roaf et al. 2009; Wood 2008; Wood 2007; Ali & Armstrong 2010; Al-Kodmany & Ali 2013; Collins et al. 2008; Trabucco 2011; Frechette & Gilchrist 2008; Leung & Weismantle 2010; Yeang 2008; Watts & Kimpian 2012; Tavernor 2007; Murray 2012; Murray 2013; Oldfield et al. 2009; Wener & Carmalt 2006; Koolhaas 2008; Keating et al. 2012)

3.4. Conclusion on sustainable tall buildings

In spite the tall building is a relatively new typology, it has gone through very significant development throughout its life, and shows a massive global uptrend in terms of height and annual number of constructions.

Sustainable building is a recently born, strongly evolving idea with – yet - many obstackles and uncertainities in its way, although its importance is not questionable.

Tall buildings' raison d'etre has constantly been questioned by critics since the birth of the typology, but – so far – they overcame every physical hurdle in their way towards the sky.

The question whether tall building can be considered as a sustainable typology is recently up on debate. As the stacked tables of "weaknesses" and "threats" are indicating, there is currently many things in the way, urging change. The weaknesses are mostly associated with almost exactly the same things tall buildings can benefit from, their height, cost, environmental and social impact. Many of yesterday's tall building developments were either built solely on speculative foundations or were driven by urging social problems paired with lack of financial funds. These projects are a disgrace for cities and societies and are – no wonder – denied by public opinion. The general cost premium for-, and the pressure tall buildings put on environment and infrastructure is also – rightly – criticized. The negative social trends of densification – although an external factor - ; overcrowdedness, isolation, lack of communal sense is sometimes also blamed on high-rises. Broadly speaking, the phenomenon of greenwashing, waste of energy, money and resources are rightly associated with tall buildings – particularly the ones built in the middle of desert. One can agree that these reasons are mostly based on a retrospective view, but still weight much in terms of sustainability.

However – in terms of sustainability - there are tremendous amount of strengths, benefits and opportunities of tall buildings which provides a positive contrast to the above written. Tall buildings have ever been symbols of human development, strengthening identity and making people proud of what they are. As SOM's Bruce Graham once said, "A beautiful building makes man proud of being man." In fact, we could not imagine today Manhattan or Hong Kong, or any other metropolis without skyscrapers. Being available to comfortably host many people over a small piece of land, they are probably the most effective tools in light of the increasing population and densification. Moreover, there are already very good built examples for creating liveable and useful public spaces in order to increase social sustainability. Density is actually proven to be a way to go in terms of sustainable development, as dense cities are very effective in reducing transportation CO_2 emissions, and in preserving natural environment. There are more and more examples of developments with much respect to environment, people and cultural heritage, we can take it as a trend for the future. There is enormous potential in energy savings through tall buildings. The “opportunities” section is discussing several promising solutions available especially because of height. Intention to improve energy efficiency is as strong as solutions for net-zero energy skyscrapers are already proposed. As technology is constantly developing, skyscrapers will ever be the first to employ innovative and high-tech solutions for a more sustainable built environment.

Few would argue that there are at least as many reasons in favor of tall buildings than against. The big difference is that the reasons “against” are merely the reasons of past, while the reasons “for” are dominantly reasons of the future.

Sustainability assessment tools and methods are in a very intensive evolution today. The way leads towards very comprehensive, life-cycle based assessment methodology addressing every dimension of sustainability. As today is about criticism, debate, while heavy research and evolution, tomorrow will likely justify sustainable tall buildings.

4. Hanoi case study – Vietnam Securities Building

Figure 31 - Vietnam Securities Building - Early Visualization – (curtesy of TT-Associates)

4.1. Introduction

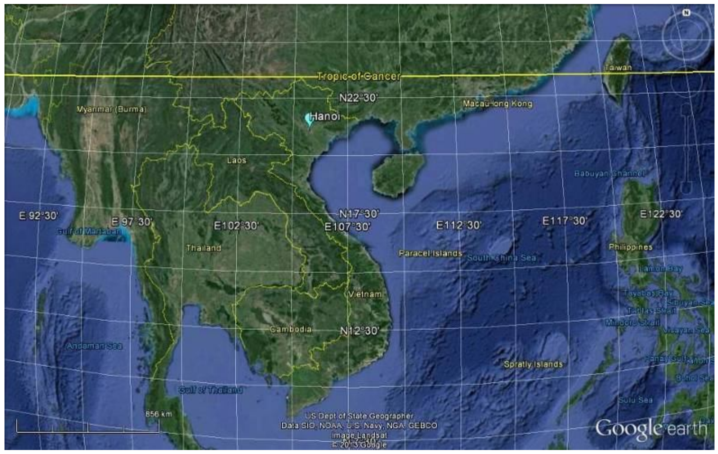


Figure 32 – Vietnam and South-East Asia

The present chapter's aim is to present a practical case study from the market in order to support previously indicated aspects of tall buildings and sustainability. The presented study was done in 2013 by the author on behalf of TT-Associates Architecture and Construction JSC, in Hanoi, Vietnam. (Figure 33)

Figure 33 - Hanoi

The subject of the study is related to an office building project on Hoàng Quốc Việt street, North-East of Hanoi.(Figure 34) The project that time was held up in design development phase, waiting for further permissions to continue. Meanwhile, TT-Associates was asked to prepare a proposal for achieving a green certification with the then accepted building design scheme.

The objective of the proposal was as follows:

1. To choose an appropriate green certification system for the building;
2. To propose a desirable level of certification;
3. To propose necessary design and technology changes accordingly;
4. To quantify the possible benefits in terms of cost and resource use.

Figure 34 – The site on Hoan Quoc Viet street, North-West of Hanoi

4.1.1. Vietnam

The Socialist republic of Vietnam is located in South-East Asia with a population close to 90.000.000 people. The capital is Hanoi is the second biggest city of Vietnam with a population of 6.500.000 people, and with close to 2000 people/sqkm, being one of the densest cities of SE Asia.

As of the history, Vietnam was changing between Chinese and Vietnamese rule until 938, then ruled by Vietnamese Royal dynasties, followed by the French colonization from 1858 – 1945. The WWII separated the country to North- and South Vietnam, leaving a long time without peace for the country. Finally after the Vietnam War, North Vietnam declared the victory and reunited the country in 1975 with the capital of Hanoi. Thanks to 1986's economic reform – the "doi moi" –, the economy became one of the fastest growing economies of SE Asia and the World. In spite of the crysis of the late 2000s, Vietnam's economic growth remained more than 5% per annum.

4.1.2. Geography, climate and ecology

Vietnam is located on the eastern Indochina Pennisula having a coastline close to 3500 kilometers, and spanning largely to North and East, from 8° to 24°latitudes (Hanoi laying on the **21°** latitude). The two main rivers are the Red River to the north running across Hanoi, and the Mekong river to the south, with its delta located around Saigon.

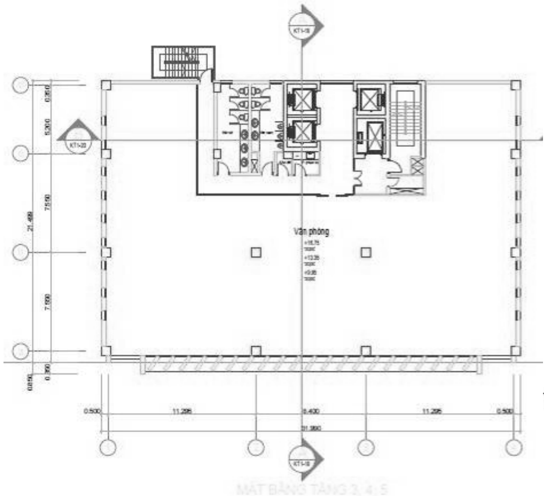
While the southern part of the country stretches across the wet tropical climate zone, the northern part – including Hanoi – is **warm humid subtropical**. There is basically two seasons, with a distinctively wet Summer ranging from May to September. Rain is a very significant aspect to consider, as the average annual rainfall is around **1700 mm** (almost three times more than for Budapest), with more than **15 rainy days/month** in August. The annual daily mean temperature is **24°C** (10.4°C for Budapest), with average high daily temperatures of around **32°C** (15°C for Budapest) during the Summer. Winters are relatively chill, still the average daily mean temperature is close to 20°C. Humidity is relatively high, as the annual average is **79%.**

Winds mainly prevail from South-East, East direction, with most frequent wind speeds between 10-20 km/h. The annual solar irradiation is around 1500 kWh/m^2.

Hanoi is one of the most polluted cities in SE Asia. Water is generally not potable mainly because of the presence of arsen, ammonium and ecoli bacteria. The air pollution is around 200 mg/m^3, which is approx. 10 times the WHO limitation. Noise pollution is also considerable, it ranges approximately around 72dB on streets like Hoàng Quốc Việt (based on (Dang & Hong 2007)).

4.1.3. The Building

The building is a high-rise office building with 17 storeys above- and 3 storeys underground, with an overall building height of almost 70 meters. The structural system is reinforced concrete skeletal frame (rigid concrete frame, according to Figure 15) resting on pile foundations, as the overwhelming majority of Vietnam construction practice assumes. The service core is located on the north side of the building. The south facade is totally glazed, with a fixed structural shading system spanning across 3 to 4 storeys vertically. The eastern and western facades' window-to-wall ratio is around 50%, while the northern facade is around 20-30%. There is a significant roof terrace area of 550 sqm.



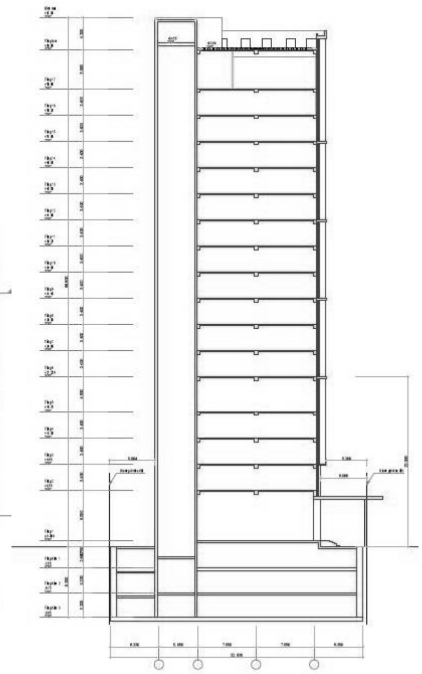


Figure 35 - Standard floor plan
Figure 36 – Section

4.2. Choosing a certification system/rating tool

Neither the client, nor the firm had previous experience with green design or green certification systems; hence an initial research necessarily had to be performed in order to decide which available rating tool suits the project the best.

The main available rating tools in the area were found to be LEED(USA), BREEAM(UK), CASBEE(JAPAN), GREENSTAR(Australia), GREEN MARK(Singapore) and a relatively new Vietnamese rating tool – LOTUS. However the company suggested LEED, GREEN MARK and LOTUS for further evaluation.

As seen in Table 1, there is a significant difference in the compared rating tools' "age", although the main criteria is merely identically based on green building principles; with LOTUS as an example aiming for slightly more aspects.

LEED is arguably the best marketed and most recognized certification system around the world with thousands of buildings already certified. The worldwide recognition was strong argument "for", in terms of brand value, security and statistical benefits.

The Singaporean GREENMARK is considerably younger and less recognized rating tool, mostly based on Singaporean standards; hence most of the certified buildings lay within the borders of Singapore and Malaysia. However, Singapore is relatively “close” in terms of Vietnam standardization, building practice, materials, available products, etc, which was certainly the strongest argument “for”.

LOTUS is a newly introduced rating system in Vietnam, developed by the Vietnamese Green Building Council. There were by the time only several projects under assessment, but - for example - no new office buildings yet. Three main strengths could be identified in case of LOTUS:

- First, it was developed especially for Vietnam in terms of available consultants, building code compliance, locally available materials, construction practice, etc.
- Second, it was merely based on years of other rating tools’ practice, which assumes that it would “learn from their mistakes” and desirably answer questions which were unanswered before.
- Finally, it is considering more aspects more or less related to sustainable building:
  - In Waste&Pollution it addresses building sewer discharge, recycled construction and demolition waste or refrigerant use in systems and appliances;
  - In Adaptation&Mitigation, it addresses bycicle parkings, locally produced materials, links with public transport system or structural disaster resilience;
  - In Community, it addresses public consultation, heritage preservation assessment, service availability radius or the distance of working staff residences;
  - In Management, developer is obliged to perform an Eco-Charette or to provide a Building User Manual.

Table 4 – Considered rating systems in comparison (table by author)

LEED (USA)	GREENSTAR (Australia)	GREENMARK (Singapore)	LOTUS (Vietnam)
2000	2003	2005	2010
-Sustainable Sites -Water Efficiency -Energy&Atmosphere -Material&Resources -Indoor Air Quality -Innovation&Design	-Management -Indoor Comfort -Energy -Transport -Water -Material -Land Consumption & Ecology -Emissions -Innovations	-Energy Efficiency -Water Efficiency -Environmental Protection -Indoor Environmental Quality -Other Green Features and Innovation	-Energy -Water -Materials -Ecology -Waste&Pollution -Health & Comfort -Adaptation & Mitigation -Community -Management -Innovation

In the end, following a personal meeting with LOTUS APs, final decision was made to employ the LOTUS rating tool.

Lotus is distinguishing only three categories of certification: certified, silver and gold. A maximum of 150 points can be achieved when fulfilling the perquisite criteria and the additional aspects. The weight of each category is shown in Figure 37 - LOTUS weighting categories (source: Vietnamese Green Building Council)

Categories	Weight (%)	Max Points
Energy	23	34
Water	10	15
Materials	13	20
Ecology	9	13
Waste & Pollution	9	13
Health & Comfort	13	20
Adaptation & Mitigation	8	13
Community	7	10
Management	8	12
Total	100 %	150

Figure 37 - LOTUS weighting categories (source: Vietnamese Green Building Council)

4.3. Assessment process and simulation tools

4.3.1. Assessment process

With early development design documentation, a chosen rating tool and a task to make proposal for the client, a work strategy or methodology had to be set up. The process was performed as follows:

1. Study the LOTUS criteria in order to evaluate the possible theoretical level of certification
2. Study possible general environmental design strategies to employ;
3. Associate possible design strategies with "points value" according to LOTUS criteria;
4. Associate possible design strategies with costs based on professional consultation with companies, previous projects cost data and different online sources;
5. Associate design strategies' costs with the extra points they are able to achieve, and weight them accordingly;
6. Create three "sets of strategies" according to which certification level is to be chosen
7. Define exact technical solutions associated with each strategy and quantify their energy features (such as U-values for walls and roof, SHGC (Solar Heat Gain Coefficient) for curtain walls, etc.);
8. Set up a baseline model for comparison, which is to carry the technical and energy characteristics of the average Hanoi office building in 2013. This is done based on previous project data and governmental statistics available in the office;
9. Build four different models in Autodes Ecotect analysis for the sake of comparison, using the available climate data for Hanoi (see 8. Appendix);
11. Get data on average office buildings – particularly Vietnamese – internal heat gains, occupancy schedules, energy and resource consumption characteristics;
12. Get data on the actual Vietnamese average electricity and water prices, and the price trends;
13. Get data on the proposed HVAC and lighting solutions' actual efficiencies;
14. Define the total annual energy use in terms of resources: water and electricity;

15. Calculate the annual operating cost of the building in terms of resources, and – given the price trends – calculate it for the next – first 20, then 30 - years
16. Calculate initial costs for the four models, considering the main elements' (such as superstructure, façade, walls, HVAC, roof, BIPV, water management, etc.) – based on the cost estimations performed
17. Summarize data for total initial costs, 20 years total costs, calculate payback times and visualize results on graphs.

4.3.2. Simulation tools used

Basically six "tools" were used for simulation, from which Ecotect was most exessively employed:

1. LOTUS Non-Residential Pathway Tool v1.0 – a simple excel tool for assessing possible LOTUS points
2. VGBC OTTV (Overall Thermal Transfer Value) Calculator Tool (Beta version) – an unpublished OTTV calculator tool of the Vietnamese Green Building Council - for assessing LOTUS perquisite criteria
3. WinWatt – for quick calculation of layered wall and roof thermal transmittance values
4. Philips Lighting Analysis tool – analysis on LED lighting compared to conventional lightin (available www.philips.com)
5. ONYX Solar Photovoltaic Estimation tool – estimating annual BIPV production (available www.onxysolar.com)
6. Autodesk Ecotect Analysis – for comprehensive daylighting and energy analysis of the proposed building models – mainly for calculating annual heating and cooling demand (see: Figure 38 - Screenshot from Ecotect model)

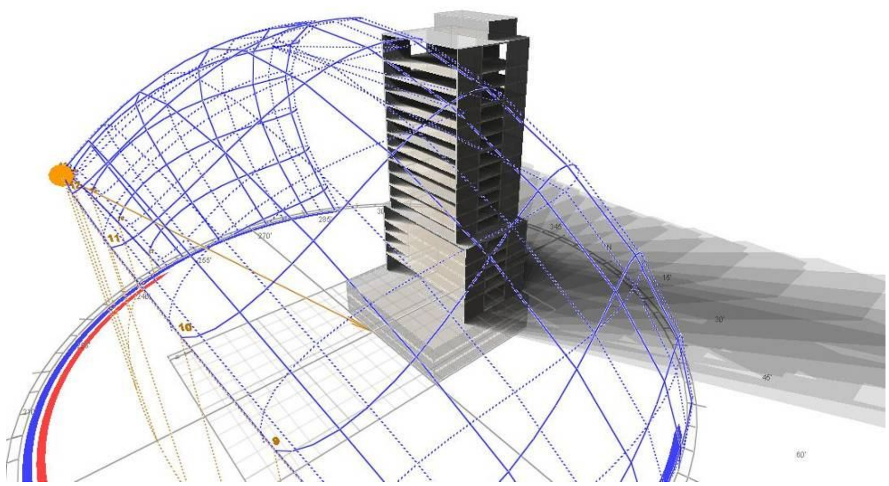


Figure 38 - Screenshot from Ecotect model

4.4. Proposed stategies and solutions

The present chapter is aiming to provide a brief overview of certain proposed technical solutions – in terms of energy- and resource efficiency.

Package 1

MINOR MODIFICATION of Building Components to reach the minimal requirements for a certification

- Correct and avoid planning & construction errors
- Upgrade Facade and MEP Systems

- Solar system
- Rainwater use

Package 2

HOMOGENOUS MODIFICATION
Upgrade of all Standard Building Components

- Substitution of Superstructure, Facade and MEP Systems
- Better construction material
- Floor Plan Modification

- Solar system
- Rainwater use Strategy

Package 3

COMPLETE GREEN BUILDING SOLUTION
Comply all requirements in Lotus Catalogue

- Substitution of Superstructure Facade and MEP Systems
- Better construction material
- Use of wall & roof insulations
- Max. use of Solar system
- Rainwater use Strategy
- .....

Figure 39 - Comparison of the proposed packages

4.4.1. Superstructure

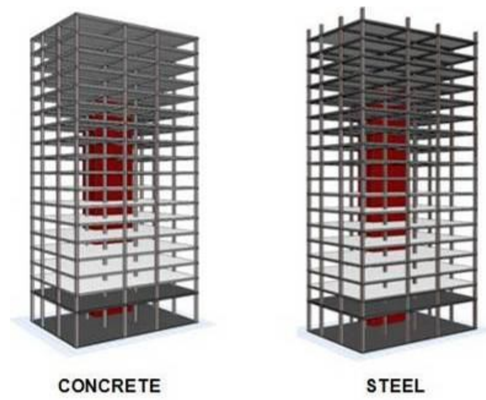


Figure 40 – Visual comparison

***Baseline and Certified* -** The baseline model – as previously indicated is a reinforced concrete rigid frame structure. Normally, there are no cement-substitutive elements, such as fly ash or blast furnace slag; hence embodied carbon is assumably high. Moreover there are concerns about the demolition safety and material recycling.

***Silver* and *Gold* -** The goal was to convince the client of the main benefits of using steel; namely using recycled material; prefabrication; precise assembly; quick assembly; durability; long life span; safe deconstruction and recyclability. For this reason, steel superstructure would have been a preferable solution for Silver, but it would be mandatory for Gold.

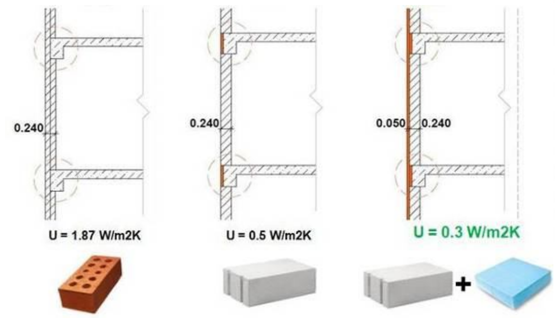
4.4.2. Vertical opaque bordering elements (Walls)

***Baseline* -** The standard practice in Vietnam today – as concrete skeletal fram is applied everywhere - is to build exterior walls of plastered clay brick (approx. 1+12+1cm), equaling a poor U value of **2.80 W/m^{2}K.** LOTUS favorizes non-baked materials, therefore clay brick is further to be substituted in silver and gold.

Certified - (1+25+1cm), plastered, two layers clay brick wall **- U = 1.87 W/m^{2}K**

***Silver* -** Plastered Autoclaved Aerated Concrete (AAC) walls (1+24+1cm) **- U = 0.5 W/m^{2}K**

Gold - Plastered Autoclaved Aerated Concrete (AAC) walls (1+24+1cm) + 5cm external polystyrene thermal insulation **- U = 0.3 W/m^{2}K**



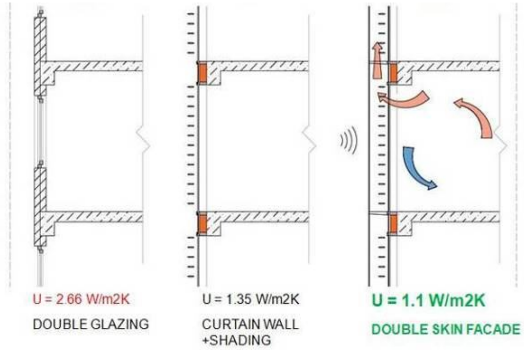


Figure 41 - Walls comparison (figure by author)

Figure 42 - Windows comparison (figure by author)

4.4.3. Vertical transparent bordering elements and shading (Façade solutions)

Baseline **-** Single glazed windows with clear float glass and no shading: **Uw= 6.0 W/m^{2}K; SHGC=0.9**

Certified **-** Double glazed windows, with clear and coated glass, internal blinds plus original structural shading solution: **Uw= 2.7 W/m^{2}K; SHGC=0.6**

Silver **-** Double glazed curtain walls, externally coated and Low-e included, with adjustable external composite horizontal blinds: **Uw= 1.35 W/m^{2}K; SHGC=0.2**

Gold - Mechanically ventilated double skin facade – internal double glazing, sealed single glazing outside, 40 cm gap, automated horizontal louvers: **Uw= 1.1 W/m^{2}K; SHGC=0.1 (solution based on** (Boake et al. 2003)**; data based on** (Partridge 2012)**)**

4.4.4. Heating-Cooling

Baseline - Split A/C system: **COP=2.0**

Certified - Split A/C system with improved **COP=3.0**

Silver **-** Centralized HVAC system **COP=3.5**

Gold - Centralized high-COP system **COP=4.3**

4.4.5. Lighting

Certified, Silver and Gold

Substitution of conventional lighting to LED lighting, in case of silver and gold, daylight responsive controls included – comparison after simulation with Philips Lighting Analysis tool shown on below.

Figure 43 Lighting initial cost and savings comparison in VND (approx. 21000VND = 1USD)

4.4.6. BIPV

Baseline, Certified – No BIPV applied.

Silver **-** Standard roof application, 140 pieces of 200W modules, each 1600x800mm in size – 20° inclination - Annual production: **27824 kWh**

Gold - Standard roof application, plus photovoltaic cladding on west facade, adding 400 pieces of the same modules – Annual production: **88694 kWh**

Figure 44 - BIPV solutions

4.5. Energy analysis results

4.5.1. Baseline

Annual heating/cooling demand: **215 kWh/sqm/a**

Other consumption(lighting, pumps, elevators, small power, etc.): **110 kWh/sqm/a**

Annual electricity consumption: **217.5 kWh/sqm/a**

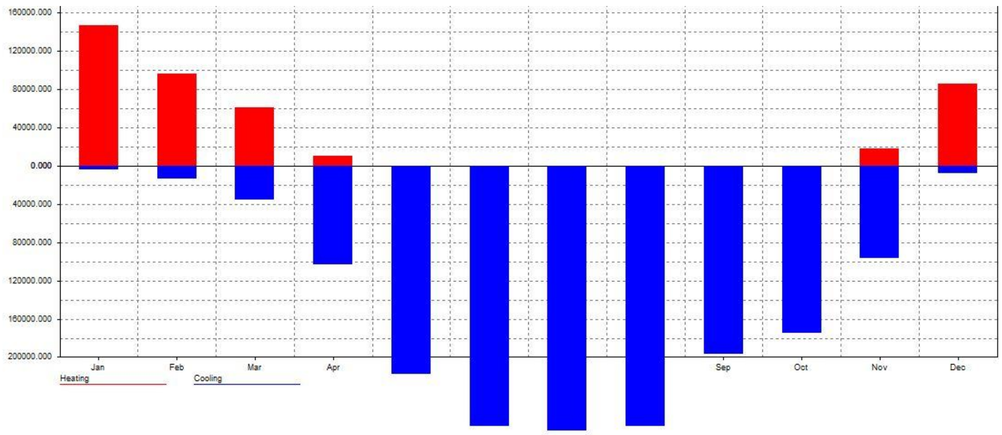


Figure 45 - Baseline annual heating/cooling loads

4.5.2. Certified

Annual heating/cooling demand: **185 kWh/sqm/a**

Other consumption(lighting, pumps, elevators, small power, etc.): **100 kWh/sqm/a**

Annual electricity consumption: **160 kWh/sqm/a**

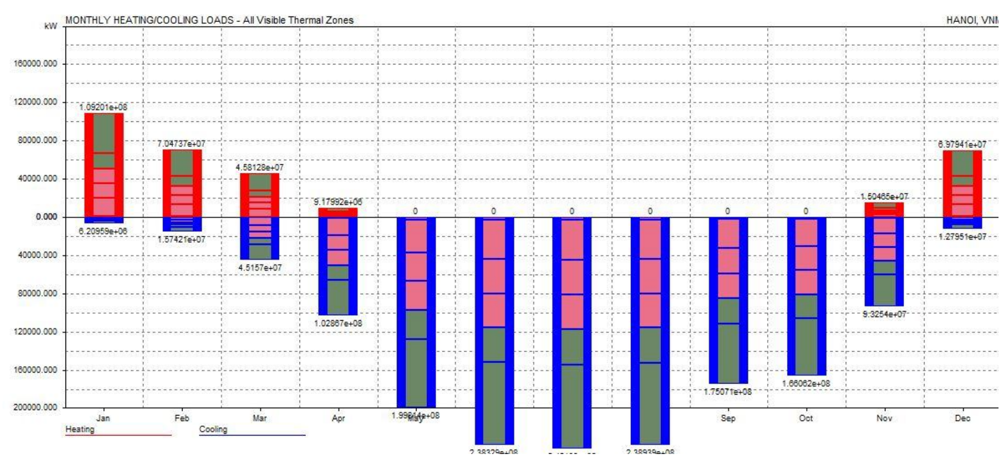


Figure 46 - Certified annual heating/cooling loads

4.5.3. Silver

Annual heating/cooling demand: **151 kWh/sqm/a**

Other consumption(lighting, pumps, elevators, small power, etc.): **80 kWh/sqm/a**

Annual electricity consumption: **120 kWh/sqm/a**

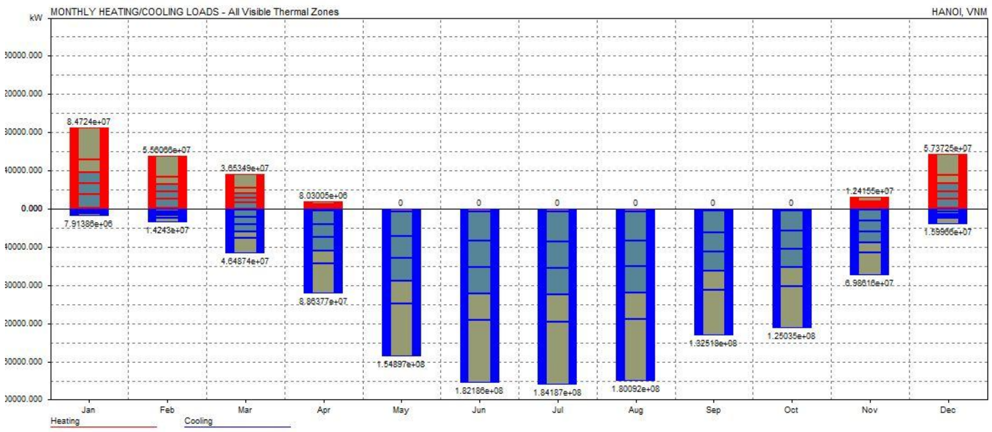


Figure 47 - Silver annual heating/cooling loads

4.5.4. Gold

Annual heating/cooling demand: **135 kWh/sqm/a**

Other consumption(lighting, pumps, elevators, small power, etc.): **70 kWh/sqm/a**

Annual electricity consumption: **95 kWh/sqm/a**

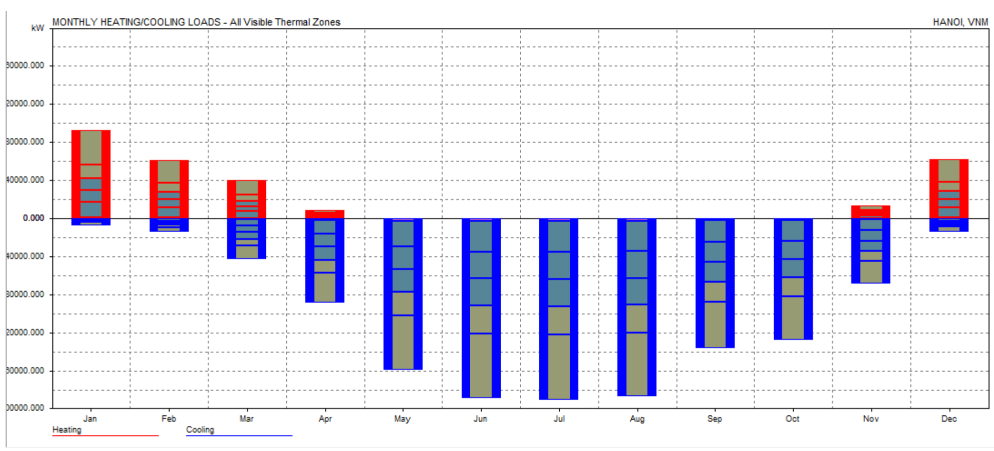


Figure 48 - Gold annual heating/cooling loads

4.6. Cost analysis results

Average water price in 2013: 12.000 VND/m^3 = 0.56 USD/m^3

Average water price growth/year: 10%

Average electricity prices in 2013: 2000 VND/kWh = 0.09 USD/kWh

Average electricity price growth/year: 15%

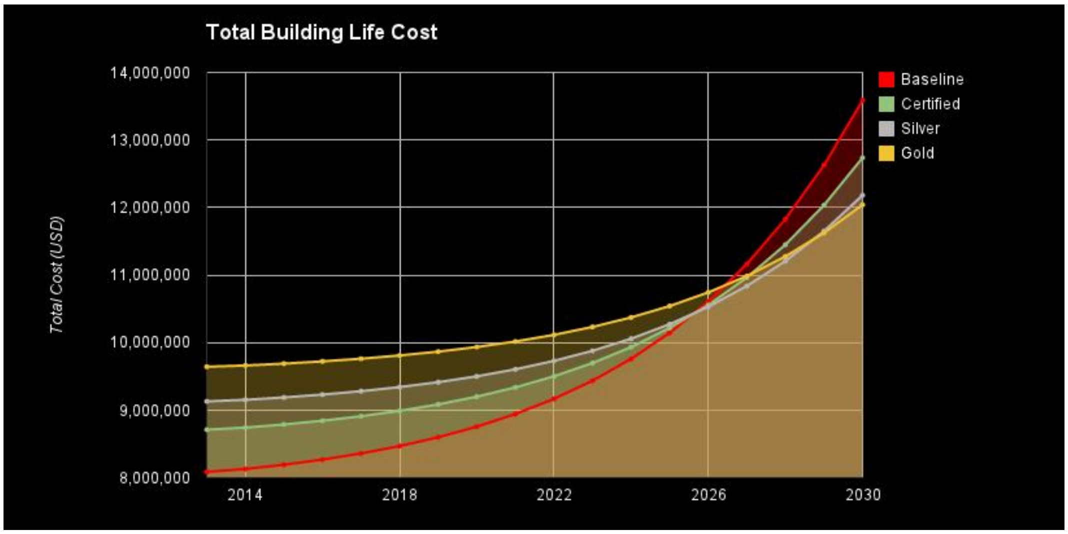


Figure 49 - Total Building Life Costs until 2030 (graph by author)

ADDITIONAL INVESTMENT*	9%	15%	22%
TOTAL INITIAL COST (USD)	8.500.000	8.970.000	9.500.000
20 YEARS TOTAL COST (USD)	14.600.000	13.600.000	13.100.000
20 YEARS TOTAL SAVINGS (USD)	1.600.000	2.600.000	3.100.000
OPERATION COST SAVING**	28%	55%	66%
PAYBACK TIME (YEARS)	11	13	14

Figure 50 - Summary of the additional investments and return rates (figure by author)

5. Conclusion

Based on a review of the current literature on the terms closely related to tall buildings, such as supertall, megatall, skyscraper and high-rise, one can agree that the terminology is blurred and the hierarchy is not clear. Accordingly, author is proposing a simplified terminology and defines a hierarchy between the terms.

A thorough review has been given on the emergence and development of tall building typology, in order to support the further understanding. Indications can be made that tall buildings are strongly associated with modern technology, their height and number of constructions show a strong uptrend, while today available technologies are able to make them more environmentally friendly, energy-efficient and cost effective.

The concept and definition of sustainable development has been thoroughly analyzed and contextualized, with emphasys on the different interpretations, changing nature, relativeness and uncertainity of the definition.

Derived from sustainable development, the context and importance of sustainable building is explained. However there are much uncertainity and criticism about sustainable buildings and their assessment today. Clear distinction has been made by the author according to the hierarchy between- and definition of the often interchangedly used terms “green building” and “sustainable building”. Green buildings are certainly contributors to sustainability, however they address a narrower perspective, basically being the “environmental leg” of sustainable building.

Is sustainable tall building a possible typology for the future, argued by many? A thorough literature review is provided about all the major arguments “for” and “against” sustainable tall buildings. Arguments were then divided to several topics aspects, such as symbolism, energy and carbon, cost, height or preservation, and were discussed briefly. SWOT analysis was performed in order to make a further distinction about the viability of sustainable tall building. The results of the analysis point out that the main arguments against sustainable tall buildings are retrospective, while the main arguments for are based on future potential. One can indicate that – if any building – tall buildings can be a sustainable building type.

A case study from the author’s recent work was examined in order to support previously presented ideas. The case study shows the importance of early sustainability considerations in terms of climate, massing, and passive design strategies. However, even if later joining the process, sustainable design elements can make a strong distinction between conventional and buildings that exhibit some attributes of sustainability. The study was performed in order to provide rough estimation of building performance in terms of energy- and resource efficiency, comparing multiple levels of "green design strategies". The results clearly show that – although further investment required - LOTUS green building certification returns the investment while addressing many aspects of sustainability. Moreover, high operational cost reduction, thus significant operational GHG emission reduction is achieved. Other beneficial – merely social – aspects unfortunately could not be addressed, however many sources indicate that energy-efficient, user-friendly, comfortable buildings are improving productivity, psychological and health conditions of occupants.

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8. Appendix

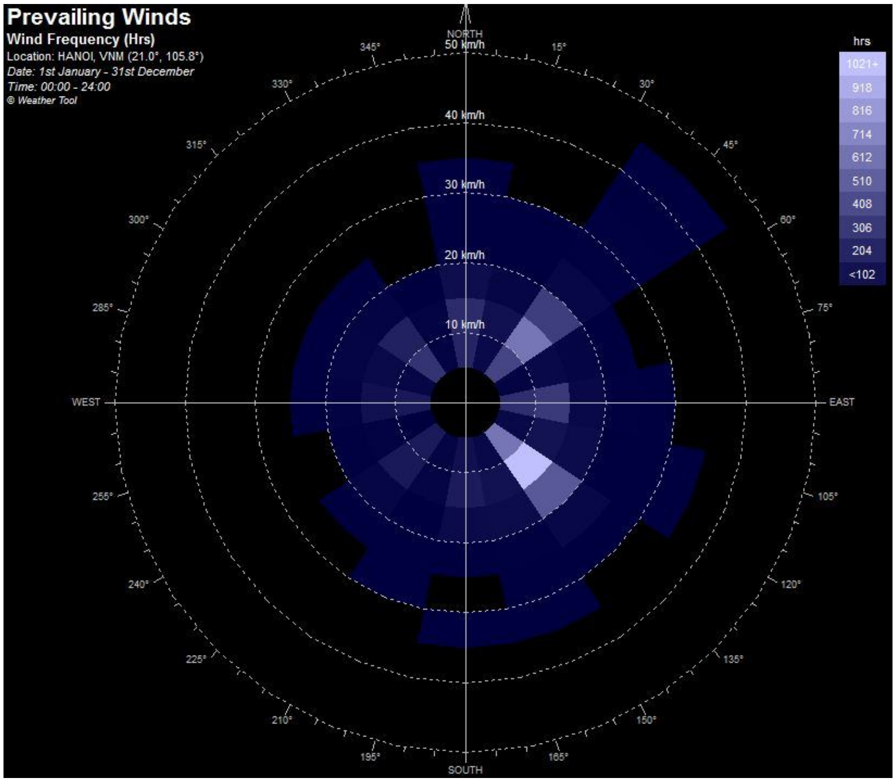

Figure 51 – Annual prevailing wind direction, speed and frequency, Hanoi, Vietnam

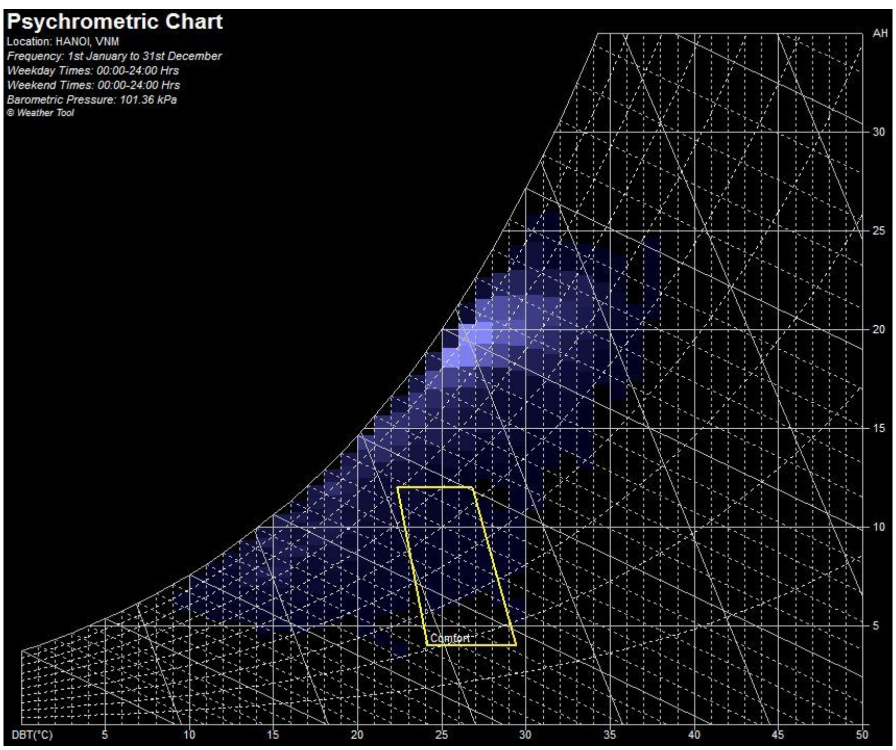

Figure 52 – Annual psychometric chart, Hanoi, Vietnam

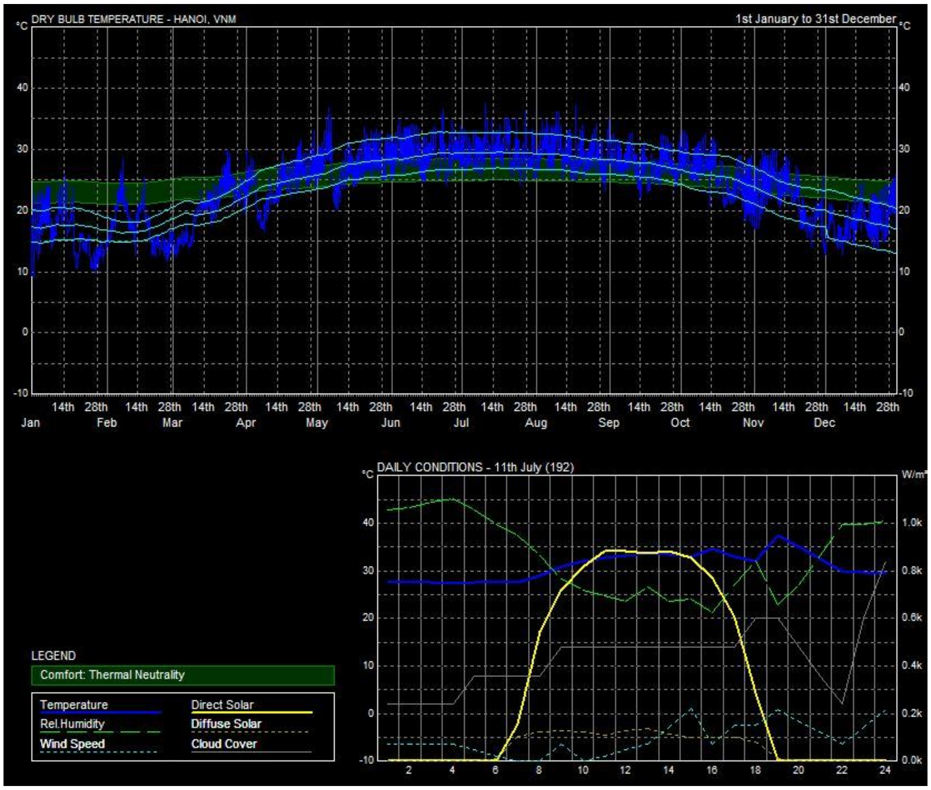

Figure 53 – Annual hourly and average temperatures and thermal comfort neutrality band

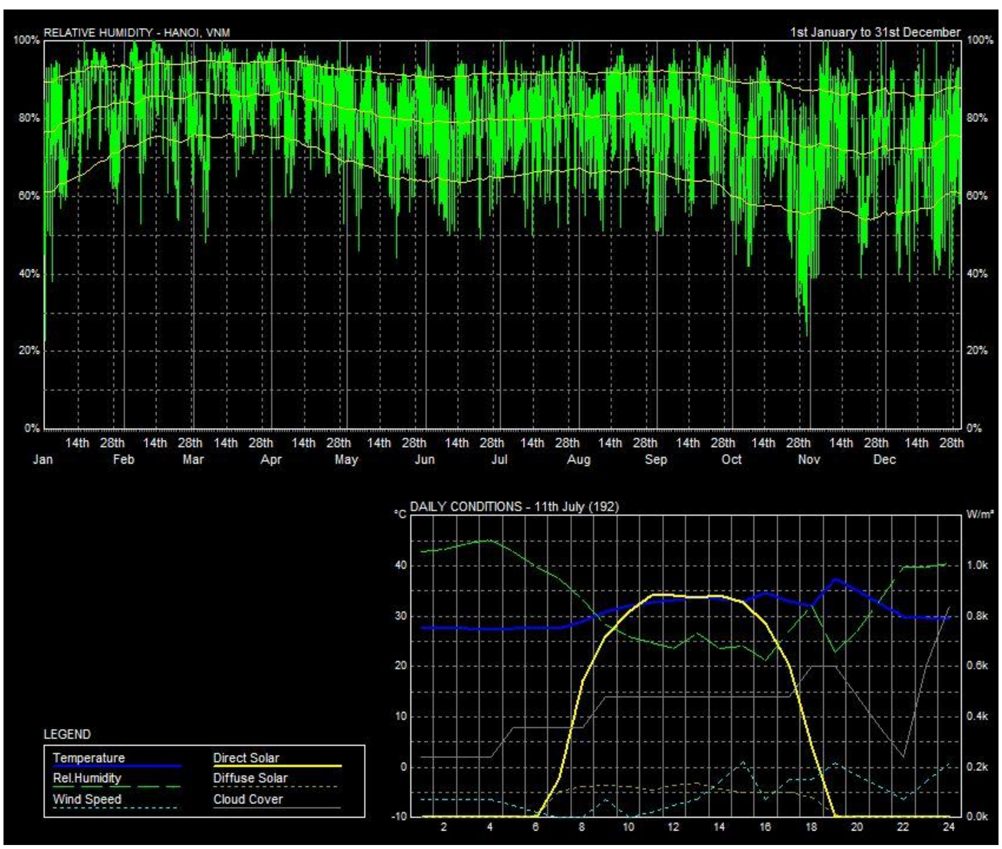

Figure 54 – Annual hourly and average relative humidity

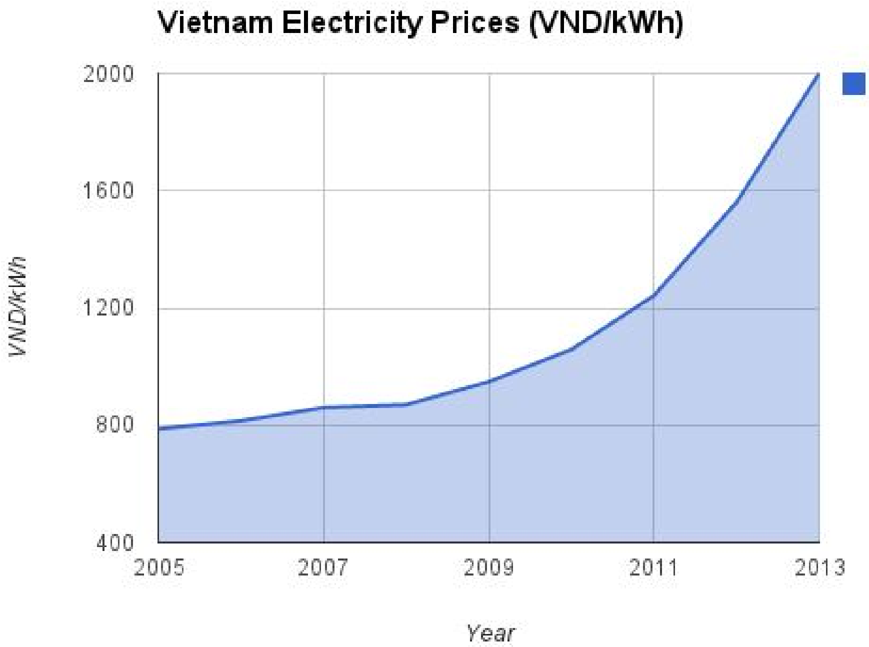

Figure 55 - Vietnam average end use electricity price trend (data source: (Tuan 2012)**)**