CHAPTER 1

ASSEMBLY OF BUILDING

1.1. Development of Tall Buildings

The term "tall building" is not defined in specific terms related to height or the number of storeys. A building is considered tall when its structural analysis and design are in some way affected by the lateral loads, particularly sway caused by such loads [1].

It has always been a human aspiration to create taller and taller structures. Ancient structures such as the Tower of Babel, Colossus of Rhodes, the pyramids of Egypt, Mayan temples of Mexico, the Kutub Minar of India and many more were apparently built as symbols of power. They were monumental, protected and were infrequently used. Today, the determining factors for buildings to become higher are mainly the economic and social factors, although human ego and competition are still playing a role.

The history of the development of tall buildings can be broadly classified into three periods. The first period saw the erection of buildings such as the Reliance Building (Chicago, 1894, Figure 1.1), the Guaranty Building (Buffalo, 1895, Figure 1.2), and the Carson Pirie Scott Department Store (Chicago, 1904, Figure 1.3). Most of these buildings were masonry wall bearing structures with thick and messy walls. The horizontal and lateral loads of these structures were mainly resisted solely by the load bearing masonry walls. The 17-storey Manadnock Building (Chicago, 1891, Figure 1.4) for example, was built with 2.13 m thick masonry walls at the ground level. The area occupied by the walls of this building at the ground level is 15% of the gross floor area. In addition to reduced floor area, lightings and ventilations are major problems associated with thick wall construction.

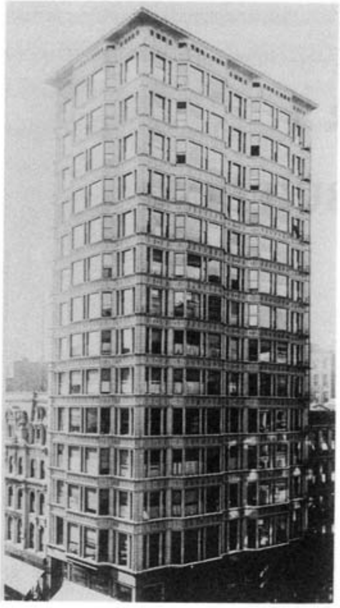


Figure 1.1. Reliance Building, Chicago, 1894.

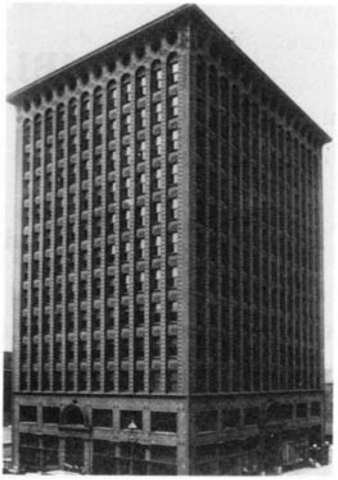


Figure 1.2. Guaranty Building, Buffalo, 1895.

Figure 1.3. Carson Pirie Scott Department Store, Chicago, 1904.

Figure 1.4. Manadnock Building, Chicago, 1891.

In the second period, with the evolution of steel structures, and sophisticated services such as mechanical lifts and ventilation, limitations on the height of buildings were removed. The demand for tall buildings increased in this period as corporations recognised the advertising and publicity advantages of connecting their names with imposing high-rise office buildings. It was also seen as sound financial investment as it could generate high rental income. The race for tallness commenced with a focus on Chicago and New York. Among the more famous buildings evolved during the period were the Woolworth Building (New York, 1930, Figure 1.5) and the Chrysler Building (New York, 1930, Figure 1.6). The race ended with the construction of the Empire State Building (New York, 1931, Figure 1.7) which, measuring 381 m with the television antenna, was the highest structure of the nineteenth century [2–6].

Reinforced concrete established its own identity in the 1950's into the third period which is now regarded as modernism in construction history. In contrast to the previous periods, where architectural emphasis was on external dressing and historical style, the third period placed emphasis on (a) reasons (b) functional and (c) technological facts [7, 8]. This new generation of buildings evolved from World Trade Centre (New York, 1972, Figure 1.8), Sears Tower (Chicago, 1974, Figure 1.9), to the recent Twin Towers (Kuala Lumpur, 1996, Figure 1.10).

The amount of materials needed in a tall building for the resistance of gravity load is almost linear with its height. However, the same materials needed for the resistance of lateral load (mainly wind load) increases as the square of the wind speed. The Sears Tower (Figure 1.9) which is about twice as tall as the Woolworth Building (Figure 1.5) has to resist wind effects four times as large as those on the Woolworth Building [9]. The third period of tall buildings saw the transition of structural systems from rigid frame to more efficient structural systems [9, 10]. The concept of channelling the gravity and wind loads using two or more separate structural systems, giving rise to buildings with flexible exterior frames and an inner core of stiff wind-bracing frames, reduces the building weight significantly. For taller buildings (in excess of roughly 60 storeys), the slender interior core and the planar frames are no longer sufficient to effectively resist the

Figure 1.5. Woolworth Building, New York, 1930.

Figure 1.6. Chrysler Building, New York, 1930.

Figure 1.7. Empire State Building, New York, 1931.

lateral force. The concept of an outer core, the perimeter structure of the building, must be activated to undertake this task by acting as a huge cantilever tube (e.g. World Trade Centre, Figure 1.8). Tubes are three-dimensional hollow structures internally braced by rigid floor diaphragms, with the cantilever out of the ground, such that overturning is resisted by the entire spatial structure as a unit and not as separate elements. To improve the shear stiffness of the framed perimeter tube, an inner braced steel or concrete tube may be added — tube in tube. The interaction causes the outer tube to primarily resist the rotation while the interior tube resists the shear (see Chapter 7 for more details). The Sears Tower (Figure 1.9) with nine square tubes of different heights "bundled" together is regarded as the most notable refinement of the tube concept.

In Singapore in the early fifties, only two buildings stood out as "high-rise", i.e. the old Cathay Building and the Asia Insurance building. Most other commercial and residential buildings were low-rise. The rapid economic growth over the last three decades in Singapore has seen an unprecedented explosion in residential, commercial and industrial development. Land scarce Singapore exhibited the necessity for the inevitable high-rise skyline, one which is now taken for granted.

Extensive coastal reclamation works have been made at Jurong, Tuas, Changi, the East Coast, stretching from Bedok to Tanjong Rhu and Marina South. Land at Jurong and Tuas were reclaimed from the swamp. Land was reclaimed from deeper waters, with marine clay substrata, at Changi, from Bedok to Tanjong Rhu and Marina South. Due to the urgent need for buildings, it has often been necessary to construct on these reclaimed areas almost immediately. The problem with excessive building settlement or large negative skin friction becomes critical.

1.2. Building Performance and System Integration

Performance is the measurement of achievement against intention. Building system integration is the act of creating a whole functioning building containing and including building systems in various combinations [11]. The various criteria including energy conservation, functional appropriateness,

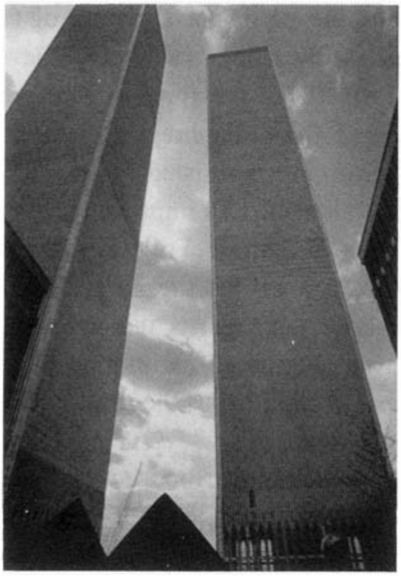


Figure 1.8. World Trade Centre, New York, 1972.

Figure 1.9. Sears Tower, Chicago, 1974.

Figure 1.10. Twin Towers, Kuala Lumpur, 1996.

strength and stability, durability, fire safety, weathertightness, visual/acoustical comfort and economic efficacy, are only delivered when the entire building performs as an integrated whole [12]. Understanding the combination effect of the various systems on the delivery of each performance is thus important.

With buildings getting taller, more sophisticated and intelligent, integration between various aspects in physiology, psychology, sociology, economics, as well as the available technology is needed. A building needs to perform the functions of building enclosure against environmental degradation through moisture, temperature, air movement, radiation, chemical and biological attack or environmental disasters such as fire or flood. It also needs to provide interior occupancy requirements and the elemental parameters of comfort. Hartkopf [12] classified performance into six mandates: (1) spatial performance, (2) thermal performance, (3) indoor air quality, (4) acoustical performance, (5) visual performance and (6) building integrity. To achieve these performances requires good integration among all participants involved in the building process, from developer, designers, building professionals, fabricator to workmen on the site.

Building professionals nowadays are often required to participate right from the planning and design stage. In the case of design and build contract for instance, the contractor is responsible for both the design and construction of a project. It is thus important that a building professional understands the implications of these performances to the design, construction as well as maintenance of a building. Among others, consideration should be given to the following:

Structural Problems of Construction:

- — Loadbearing: stability develops during construction (except for considerations of temporally works e.g. formwork).
- — Frame construction: temporary provisions for stability, rigid joints, bracing, shear walls.
- — Special structure: bridges, space structures, provision for erection stresses, sensitivity to construction or uneven loading.

Safety Margins, Construction Instability:

— Safety margins: reduced by accurate design.
— Failure characteristics: e.g. *in situ* versus prestressed.
— Construction instability: appropriate temporary support, e.g. shell construction, air-stabilised construction.

Settlement of Structures:

— Ground conditions: flexibility of structure where settlement occurs.
— Effect on building design and detailing.

Services Installation:

— Relationship to building use and structure.
— Provision of services
  - horizontal, vertical, ducting, ceiling spaces, penetration of slabs, beams etc.

— Integration of installation.

Table 1.1 illustrates the various performances required of a building.

Table 1.1. Building Performance Mandates [2].

Building Integrity	Thermal Comfort	Acoustic Comfort	Visual Comfort	Air Quality	Spatial Comfort
moisture temperature air infiltration radiation & light chemical attack biological attack fire protection wind, settlement	air & radiant temperature humidity air speed	reverberation & absorption vibration	artificial light & daylight	ventilation, natural & artificial mass pollution energy pollution	flexibility hidden services circulation

1.3. Cost, Quality and Time

The triangle involving cost, quality and time is well known with priority between the three relying on the client's objectives. Buildings related to commerce such as shopping complexes may require that time be the top priority so as to have the building commence operating before certain festive seasons, or in certain cases, to reduce financing bills etc. With a limited budget, cost may be the top priority. Quality may be emphasised in cases where the building itself is monumental or reputable in terms of height, architecture, appearance and background.

It is important that economic buildings do not necessarily mean unsafe buildings. Through proper design, management and execution, an economic building can provide the required standard at the lowest cost.

The basic resources for a building are: (1) money, (2) labour, (3) materials and (4) machinery. Labour must be employed and paid, materials must be purchased and machinery must be bought or hired. The manner in which materials are incorporated in the fabrication and structure of a building at the design stage and in which materials are handled and equipment deployed on the site or in a factory all affect the degree of expenditure of money and the overall economy of a building project [13, 14].

1.4. Building Regulations and Control

Building regulations are documents laying down the minimum requirements and standards that a building must comply with to ensure that the safety, hygiene, stability and level of amenity are compatible with environmental and social requirements at the time of construction and throughout the lifetime of the building [15–19].

The history of modern building legislation goes back to 1845 in the U.K. when the first Public Health Act was passed. Housing was then the primary concern and the defects to be fixed were mainly damp, structural instability, poor sanitation, fire risk and lack of light and ventilation [15]. In the U.K. in 1877, the first model bylaws were produced as a guide for local authorities on whom lay the responsibility for setting and enforcing minimum standards.

These applied only to new buildings, but in 1936 new legislation was enacted covering all buildings and requiring all local authorities to make and enforce "building bylaws". At this time, although guidance from central government was given, local authorities still held direct responsibility for building standards and issued their own bylaws which, although generally similar, had individual differences. The breakthrough came with the issue of the 1952 Model Bylaws, series IV (amended 1953) in which a different technique of control was used whereby standards of performance were stated, and these formed the mandatory part of the bylaws. A description of the actual structural minimal, which previously had been mandatory, were now contained in the so-called "deemed to satisfy provisions", leaving the way open for other newer methods and materials to be used, provided their performance could be established. This system has enabled increasing reference to be made to advisory publications such as British Standard Specifications and Codes of Practice.

In Singapore, the Building and Construction Authority (BCA) of the Ministry of National Development plays an important role in building control, especially after the collapse of Hotel New World in 1986. The Building Control Act empowers the Minister for Law and National Development to make such regulations for carrying out the purpose and provisions of the aforesaid Act in the interest of public health and safety. It sets out the scope of the regulations, namely, the submission of plans and specifications of works, the authorisation of persons qualified to submit the same and their duties and responsibilities, the construction, alteration and demolition of buildings with special emphasis on frontage, airspace, lighting, air conditioning, ventilation, height, approaches, entrances and exits, damp proofing, building materials, structural stability, drainage, sanitation, fire precautions and provision of car parking facilities.

The Fire Safety Bureau, a division of the Singapore Civil Defence Force, is another important authority in building control. Clearance from the Fire Safety Bureau is required for both the submission of plans as well as the application for the temporary occupation permit (TOP). Based on the Code of Practice for Fire Precautions in Building [20] and others, the authority scrutinises the design in terms of the escape exits, structural fire precautions, site planning and external fire fighting provisions, electrical power supplies, fire fighting systems, mechanical ventilation and smoke control systems.

There are also other subsidiary legislations and regulations imposed by other ministries. Examples are the "Environment Public Health Act" by the Ministry of Environment, and the "Factories (Amendment) Act" and "Factories Regulations" by the Ministry of Manpower.

1.5. Constraints and Resources

In Singapore, the combination of constraints and resources are probably unique compared with elsewhere. For this reason techniques of design and construction may be used successfully here where they have been considered unsuccessful elsewhere and vice versa.

The basic constraints on the construction process are control mechanism, construction resources, locational constraints, client requirements and restrictions, and design.

The basic resources are finance, time, technology & information, administrative & managerial skill, materials, labour and plant.

In Singapore, the government has been monitoring these constraints and resources through the then Construction Industry Development Board (CIDB) formed in 1984. In April, 1999, CIDB merged with Building Control Division of the Public Works Department (PWD) to form the Building and Construction Authority (BCA). The primary role of BCA is to develop and regulate Singapore's building and construction industry. The four key thrusts of BCA are:

- improving quality and productivity through high standards of excellence and the use of innovative construction technology,
- raising skills through training and testing to develop a professional construction workforce,
- ensuring building works are designed to comply with regulations and built to high safety standards,
- supporting industry growth through resource and information management.

1.6. Environmental Requirements

The exterior and interior environmental issues covering energy, resources and materials, transport, pollution, noise, landscape and ecology, waste management, etc. have been much discussed [21–26].

The effect of cyclic temperature and moisture, radiation such as ultraviolet light on building materials can be significant:

Temperature: The temperature range in the tropics is small compared with temperate countries with summer and winter as the two extreme seasons. However, joints are still very important on large areas and exposed faces and in some cases the requirements may be higher than those required in overseas design due to factors such as thermal shock. Thermal shock may also act to cause cracking of surfaces through the release of stresses built into materials during manufacture, e.g. bricks.

Sunlight: Ultraviolet light is considered significant in the deterioration of mastics, sealants, plastics and paints, etc. More details on the effect of ultraviolet on facade and roof coverings are discussed in Chapters 8 and 9.

Moisture: Since freezing may be ignored except for special applications, some design requirements used overseas are not significant here. Cyclic absorption and evaporation together with high temperature and humidity lead to problems with micro-organisms and fungi, etc. Detailing to minimise staining is important. Rising damp from the ground is common [27].

With tall buildings getting more sophisticated, so too the building users. They no longer tolerate thermal discomfort, glaring illumination, poor ventilation, energy wastage, poor acoustics and excessive noise, etc. Much improvement in environmental control has been made since the late eighteenth century with the advancement in building services. Rapid improvements are also seen in other areas e.g. activating the building fabric to provide the most favourable interior environment by controlling the utilisation of solar energy.

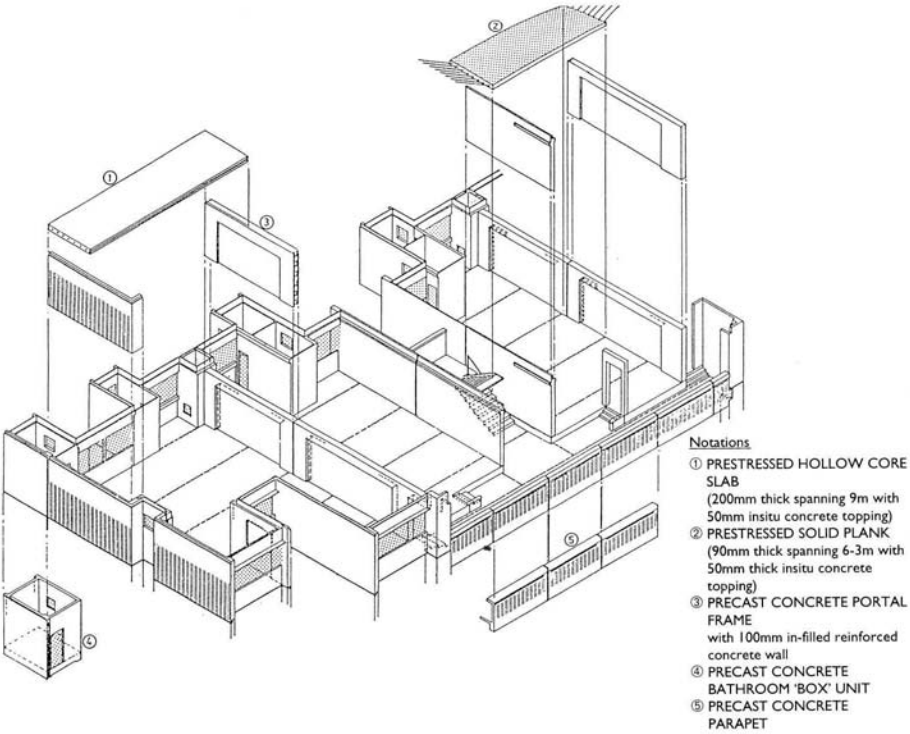
1.7. Industrialisation

Industrialisation in building is often related to prefabricating in a plant the maximum number of building works with the appropriate equipment and efficient technological and managerial methods. The greater the number of prefabricated components that are produced in the plant, the fewer the onsite works required. This will significantly reduce the dependence on skilled labour, the weather, the site and various other constraints [28–30].

The immediate benefits that can be derived from industrialisation are obvious:

- Saving in manual labour onsite especially in skilled trades such as formwork, masonry, plastering, painting, carpentry, tiling and M&E.
- Faster construction process.
- Higher quality of components attainable through careful choice of materials, equipment and quality control.

The application of industrialisation in Singapore was first attempted on 1963. It was implemented in a large scale in the 1980's. Figure 1.11 shows the basic sequence of erecting the main component of a building based on the system adopted by White Industries. In this system, horizontal units and volumetric units which include hollow core slabs, staircases, balcony spandrels, refuse chutes, bathroom units and service ducts are erected first. The floor slabs are lifted by vacuum suction lifters attached to the crawler crane and are placed horizontally onto the ground frames or preceding floor. They are then linked together by a tie system which includes internal, transverse and peripheral ties. Components like staircases, balcony spandrels, refuse chutes, bathroom box units and service ducts are hoisted by cables and placed in position. They are aligned and secured by dowel joints and reinforcement ties. Vertical panels like walls and frames, and internal partitions are lifted and aligned into the correct position on the floor slab by dowel bars. Packing mortar is applied to the joint where the panel is located and is held vertically by temporary props. The voids of the joints are cemented and the perimeter of the exposed joints are laid with grout seals to achieve watertightness. Structural connections in the form of tie beams are formed between vertical to vertical, horizontal to horizontal and vertical to horizontal components. When the grout to the joints or connections has hardened, the temporary props are removed. A 50 mm reinforced screed is then cast over the floor slab to ensure continuity. To complete the whole



Notations
① PRESTRESSED HOLLOW CORE SLAB
(200mm thick spanning 9m with 50mm insitu concrete topping)
② PRESTRESSED SOLID PLANK
(90mm thick spanning 6-3m with 50mm thick insitu concrete topping)
③ PRECAST CONCRETE PORTAL FRAME
with 100mm in-filled reinforced concrete wall
④ PRECAST CONCRETE BATHROOM 'BOX' UNIT
⑤ PRECAST CONCRETE PARAPET

Figure 1.11. Isometric view of structural system by White Industries Pte Ltd.

building, the roof structure is erected with roof panels, parapet walls, roof water tank beams and panels.

1.8. Robotics in Construction

The casting, erection, jointing, connection and finishing of building components require a high level of skilled manual work onsite. The problem with the shortage of skilled personnel and the need to increase productivity in the industry has prompted research and development into robotics in the construction industry.

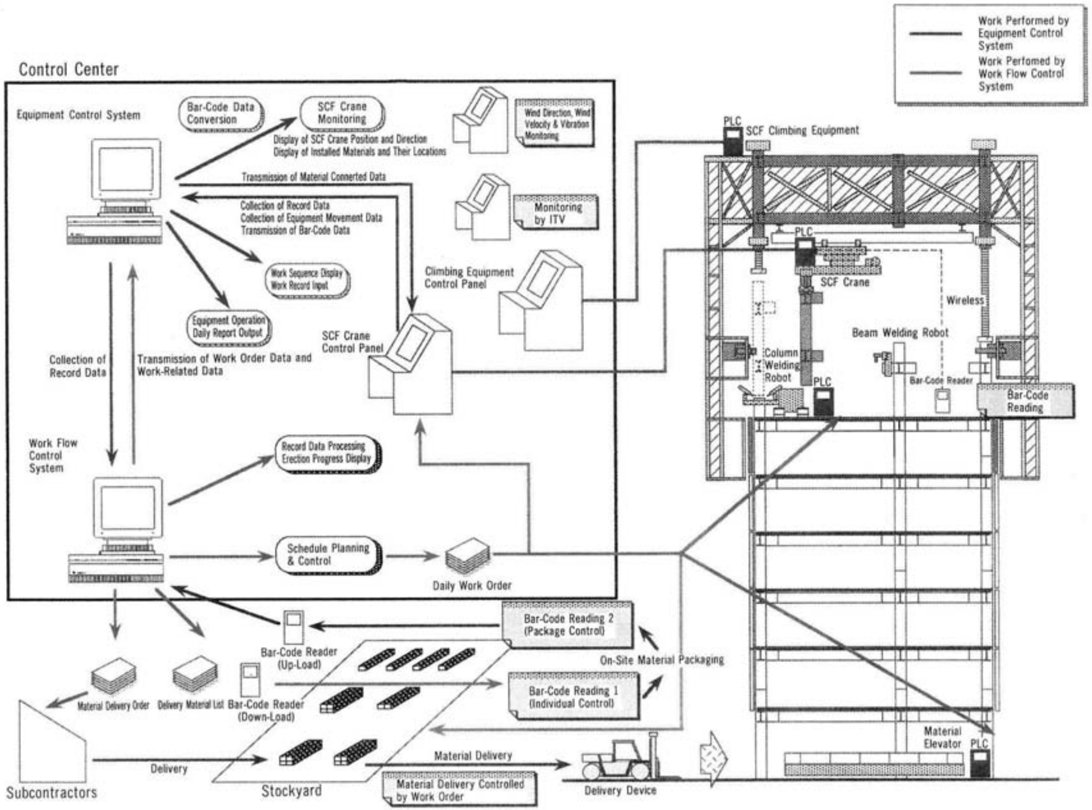
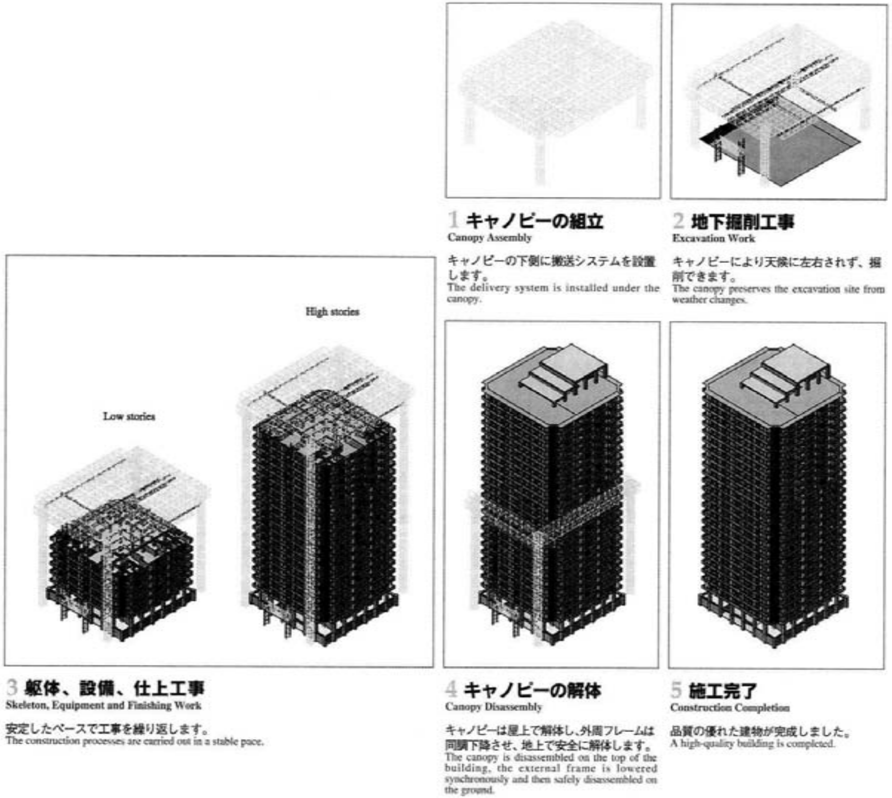


Figure 1.12. An example of robotised construction — Construction Factory (courtesy: Obayashi Corporation).



1 キャノピーの組立
Canopy Assembly
キャノピーの下側に搬送システムを設置します。
The delivery system is installed under the canopy.

2 地下掘削工事
Excavation Work
キャノピーにより天候に左右されず、掘削できます。
The canopy preserves the excavation site from weather changes.

3 躯体、設備、仕上工事
Skeleton, Equipment and Finishing Work
安定したペースで工事を繰り返します。
The construction processes are carried out in a stable pace.

4 キャノピーの解体
Canopy Disassembly
キャノピーは屋上で解体し、外周フレームは同調下降させ、地上で安全に解体します。
The canopy is disassembled on the top of the building, the external frame is lowered synchronously and then safely disassembled on the ground.

5 施工完了
Construction Completion
品質の優れた建物が完成しました。
A high-quality building is completed.

Figure 1.13. An example of robotised construction — Big Canopy (courtesy: Obayashi Corporation).

Recent progress in robot technology enables robots to perform sequences of tasks onsite, by interaction with its environment through electronic sensors. An example is Obayashi's "Super Construction Factory" which integrates the concepts of factory automation into the building site for steel structures (Figure 1.12). Building components and materials are delivered to the floor under construction through elevators and are lifted to the exact location of the floor by cranes. Welding and fastening are then carried out by robots. Upon completion of one floor, the factory is jacked up through an internal climbing system to commence work on the next floor.

Another system for reinforced concrete building named "Big Canopy" integrates technologies of climbing canopy, prefabricated components, automated assembly and computerised management systems (Figure 1.13). The canopy provides protection for the floor under construction from unfavourable weather and environmental conditions. Independent tower crane posts are used as four columns supporting the canopy. The rise of the canopy is performed by the climbing equipment of tower crane. Vertical movement of materials to and from the working story is by the use of lifts and horizontal movement by hoists. The movement of the hoists is entirely automated to improve work efficiency.

Mobile robots have also been used in isolated applications such as wall tile inspection [31], paint/concrete spraying, high pressure water jetting, concrete floor surface finishing, reinforcement laying etc. A survey of the use of construction robotics in Japan shows that the best returns are from tunnelling applications because of the hostile working environment and the shortage of skilled workers [32].

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