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SCHOOL OF DESIGN AND BUILT ENVIRONMENT

Study title TOWERING INFERNO: The regulation of fire safety and its impact on the design of tall buildings

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This Study was submitted as part of the requirements for the award of

BACHELOR OF ARCHITECTURE

In the

SCHOOL OF DESIGN AND BUILT ENVIRONMENT

At the

QUEENSLAND UNIVERSITY OF TECHNOLOGY,
BRISBANE, AUSTRALIA

Date: 01/06/2007

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TOWERING INFERNO

The regulation of fire safety and its impact on the design of tall buildings

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ADB052 Architectural Research 2

Semester 1, 2007

Abstract

Fire safety regulations provide a significant restriction on the planning of tall buildings. The location and nature of egress points, lifts and smoke control have a measurable impact on the floor plate design of tall buildings and as a result contribute heavily to planning decisions early in the design process. This thesis will investigate the implications of fire legislation on the design and resultant form of tall buildings.

The regulation of fire safety has developed in response to a history of building fires which have caused avoidable deaths and injury, providing the basis for minimum standards which have been written into law. As economic forces drive the growth of tall buildings to higher and higher limits, the demand and pressure to provide a higher standard of building safety in the event of a fire has become more pressing and increasingly legislated.

In order to study the theoretical and practical implications of fire safety regulations on the design and the resultant form of tall buildings a series of case studies has been selected from both Hong Kong and Brisbane. These examples are all designed under different legislation and illustrate that there is a direct relationship between the legislation of building and design outcomes.

Glossary of Terms

Deemed-to-satisfy

The term used in the Building Code of Australia to describe prescriptive provisions that buildings are permitted to be designed in accordance with.

Emergency Lift

An elevator designed to function in and resist damage from various threat scenarios i.e. fire, explosion and earthquake. These lifts generally have a larger capacity and are operated by fire-fighters in the event of a fire. (CTBUH 2004)

Fire

"A state, process, or instance of combustion in which fuel or other material is ignited and combined with oxygen, giving off light, heat, and flame." (Fire 2007)

Fire engineered solution

A fundamental engineered approach to fire safety in buildings based on project specific building performance analyses in fire scenarios. (Poon and O'Meagher 2007)

Fire isolated

A compartment of a building constructed to high fire resistance level.

Market failure

A failure of the market to provide a level of safety in buildings, expected by the public (Cobin 1997)

Protected lobby

An escape stair lobby, fire-isolated from the remainder of the building.

Refuge floor

A naturally ventilated floor of a building which act as a sub-base for fire-fighters and a safe place for evacuees to rest, fire-isolated from the remainder of the building.

Smoke

The visible vapour and gasses given off by a burning or smouldering substances (Smoke 2007)

Stair

Also known as a stairwell, staircase or stairway it is a flight of steps for going from one level to another.

Tall building

A building where there are occupied floors higher than the maximum height of a standard fire engine ladder. (*High-Rise Manual: Typology and design, construction and technology* 2002)

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Acknowledgments

I wish to express my gratitude to:

Florian Heise, thankyou for spending a day of your holiday in Hong Kong sorting through plans and sections with me
Ian Mitchell, thankyou for your suggestions and guidance
Robin Howes, Ron DeVeer, Henry Peel, Chris Odgers, Ron Blake and Terry Moran thankyou for taking the time to talk to me and answer my questions.
Marshall Gerometta, Senior Editor of Emporis thankyou for your assistance in collecting information on building statistics
Fh Liu and the staff at Building Department in Hong Kong for their assistance in obtaining the plans of the Hong Kong case studies
The librarians at Queensland University of Technology and the Brisbane City Council archives thankyou for helping me to locate some harder to find resources.
Julia, Yani and Nina Liu thankyou for your generosity in letting me stay at your apartment while I was in Hong Kong.

1.0 Introduction

This thesis explores the interrelationship of fire safety regulation and architectural design and it's impact on tall buildings. The advent of fire safety regulation has been described as a process of trial and error. Historically, building height has soared in line with the growing value of land. The economic conditions that are the drivers behind the building of skyscrapers have called for a maximisation of rentable floor area and as such there is a requirement for the area necessary for fire safety to be minimised. (Yeang 1991, 22)

> *"Very tall buildings represent huge investment, not only for the company which develops them, but ultimately for the whole community… Unlike their smaller cousins, very tall buildings – say above 50 stories – are unlikely to be demolished within 60 years or so of construction … [and as such] we must strive for economy, flexibility and long life."* (Kilmister 1991, 309)

Within this thesis a history of the legislation of fire safety in tall buildings will be discussed along with a discussion of the origin of legislation and the impact they have had on the form of tall buildings. The reasons for the regulation of fire safety shall be investigated and analysed through a series of case studies of tall buildings from Brisbane, Australia and Hong Kong.

1.1 Significance

Fire safety regulations have a major impact on the planning and servicing of tall buildings and as such the decisions on where to locate these services is usually an early decision in the design process after which the majority of decisions are left to a fire engineer. The bulk of writing on this topic is from an engineering viewpoint and therefore it discusses fire safety measures in isolation from the rest of the built form. "The … vertical component and key element in designing the service core is the staircases. Their location, as a required means of egress, is often one of the decisive form-givers in any major building." (Yang 2000, 47) In identifying the impact fire regulations have on the design of tall buildings, it can be determined whether best practice is being implemented or simply the minimum requirement of the law.

1.2 Research statement

Despite the perception that high-rise building design provides a complicated problem requiring the skill of an architect in resolution, it could be argued that prescriptive fire regulation provides a limited set of architectural options in the design of these superstructures. This study intends to make evident the significant role of fire regulation in the early phase of the design process. In exploring the relationship between regulation and design, this study illustrates the restricted 'architecture' of tall buildings

1.3 Limitations

The parameters of this study are that only fire legislation relevant to the design of tall buildings has been considered. The word tall has been used to describe these buildings as they must be judged against the context of their physical surroundings and the time in which they were built.

The case studies selected to be a part of this thesis have been chosen from Brisbane and Hong Kong. These two cities have a similar climate and a legislative background with origins in the British colonial empire.

1.4 Methodology

This thesis will provide six case studies that will be analysed against fire safety legislation enforced at the time the buildings were designed and constructed. Because the design of tall buildings is a complex process involving different sites, clients, occupancies and budgets the basis of design changes from building to building meaning that a single example would be inadequate to predict general trends. The legislation applied to the design of tall buildings is also variable, regulations are continually being updated following; a greater understanding of the science of smoke and fire and the advent of death caused by major fires. The selection of case studies therefore assesses the relationship between the design of buildings and the legislation applicable to them.

1.5 Chapter overview

Chapter two is an introduction to the history of fire safety, globally and in Queensland. This chapter begins with the development of life safety legislation from the early days of tall buildings in the United States of America. As recognised by the British Joint committee of the Building Research Board and the Fire Offices' Committee in 1946, "in America, … the problem of fire protection is dealt with comprehensively in most up-to-date building codes." (1946, 7) This early history of fire legislation is followed by a more recent account of the changes and development of legislation in Australia and more specifically Queensland.

Chapter three explores the reasons why fire safety is regulated. The implications of retrofitting older buildings are discussed along with the recommendations of the USA government following the World Trade Centre incident. Other aspects of fire safety which affect the design of tall buildings are also discussed including areas of refuge, egress and evacuation and the emergence of fire engineered solutions as an alternative to designing in accordance with deemed-to-satisfy provisions.

Chapter four looks at the impact of fire legislation on the form of tall buildings. Through a categorisation of buildings into concealed services and revealed services typologies, this chapter looks at the impact such an early design decision has on the design of tall buildings. The current crop of atrium buildings, ventilated facades and the clear glass buildings are also discussed here.

Finally chapter five outlines and compares the six case studies chosen followed by an analysis of each of the case studies.

2.0 History of Fire Safety Regulations

Fires have always accompanied human habitation and over the millennia, the response to preventing and fighting fire has become more sophisticated. Early examples of this progression date back to Rome where a night patrol of slaves called a ‘vigile’ was organized to alert a neighbourhood in the event of a fire and in eleventh century France where an evening hour set the time limit for the extinguishment of all fires. The latter came to be known as a curfew meaning ‘cover fire’. (Arnold 2005, 3; Odgers 2002, 5)

The first enforced formal building regulations on the materiality of buildings were initiated after the Great Fire of London in 1666. These early building regulations mandated the use of brick or stone construction. (Arnold 2005, 3; de Veer 2007) these regulations remained

2.1 Global History of Fire Safety legislation of tall buildings

Technological developments up to 1900 gave rise to two sets of opportunities highlighting problematic issues confronting the design of large buildings. The first was a change in how building standards were enforced and the other in how through advances in technology facilitated more freedom of use in buildings. (Banham 1984, 71) It was the invention of the steel frame, elevator, electric lighting, telephone, and a willingness for business to proceed that made the skyscraper possible (Banham 1984, 72) These initial tall buildings were developed during a time with limited or no fire regulation, with only consumer expectation and property speculator generosity ensuring the provision of any fire safety provisions at all.

Prior to the 1852 there were no mandatory fire escapes in the United States of America, in fact the term fire escape referred to a temporary ladder that was wheeled to a building in the event of a fire. also present at this time were ladders fixed to the outside of buildings enabling firemen to access the roof during a fire, but these were not legislated until 1852 first in Brooklyn followed by most other cities in the USA. (Wermiel 2003, 259)

The iron balcony also came into existence at this time after a survey of tenements in New York 1856 which found that one of the many failings of these buildings was that they were fire traps. Regardless of the number of tenants, they usually only had a single staircase. This report recommended that stairs within these buildings should be built to ensure egress in case of fire, but nothing happened. A fire in one of these buildings in 1860 killed 10 people, as a response the first exit regulations of New York were written. These regulations only applied to large tenement houses and asked for either a non-combustible internal stairway or a ‘fire escape’. This law did not specify what a fire escape was or whether it had to be a permanent fixture and therefore there were many creative interpretations of what a ‘fire escape’ was. (Wermiel 2003, 260-263)

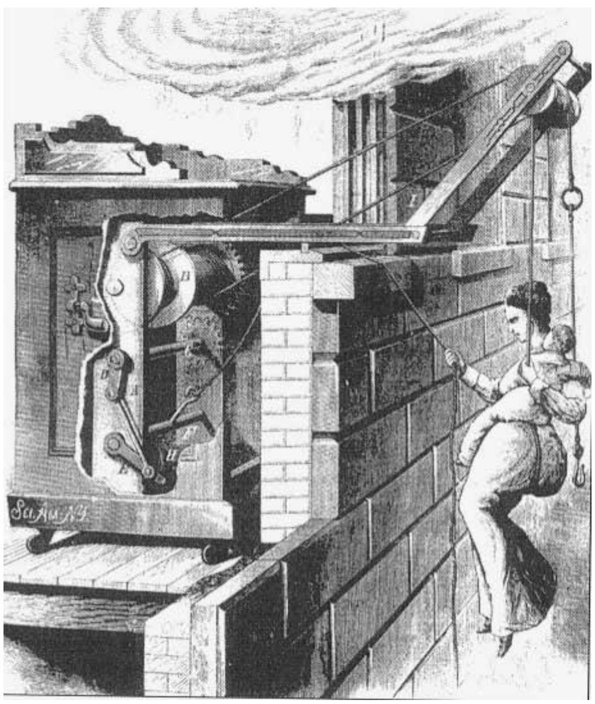

Figure 01: *“A rope-type fire escape. This one, patented in 1878, is disguidsed as a washstand.” (Lescale's Fire Escape 1878, 14; Cited in: Wermiel 2003, 262)*

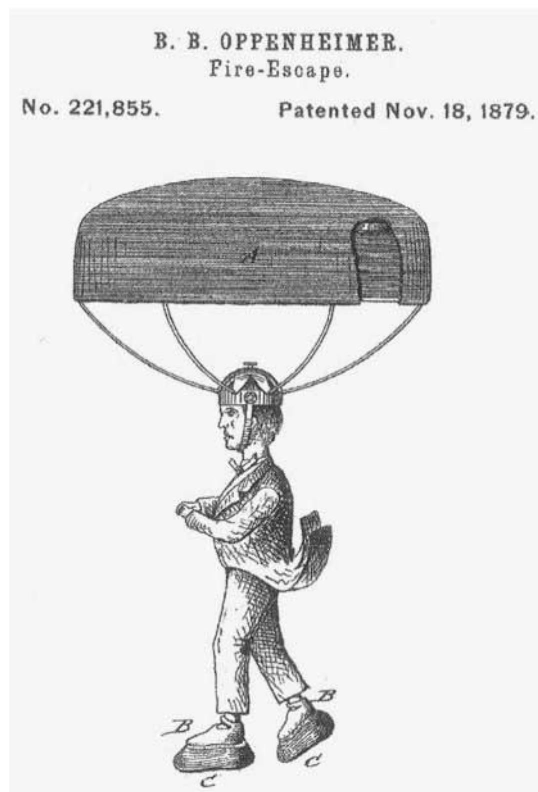

Figure 02: *“Fire escape, consisting of a parachute hat and elastic-sole overshoes, U.S. patent no 221,855 1879.” (Wermiel 2003, 268)*

Once again a major fire in Massachusetts in 1874 prompted legislation calling for the inspection and report on the means of escape from public buildings and factories. The findings from this process showed that most buildings only had one stairway with doors opening inward. The resulting 1877 Massachusetts *Factory Act,* empowered authorities to inspect buildings and order improvements to egress facilities at their discretion. (Wermiel 2003, 261) This Act was later updated in 1880 to stop disputes between inspectors and owners. These revisions included the specification that fire escapes were to be stairways and to be constructed with iron. (Wermiel 2003, 261)

Pennsylvania passed a very similar law in 1885 for external iron stairways as escapes from buildings and by 1885 Illinois also had a state wide fire escape law, calling for all buildings four stories or over to have one or more metallic ladders or stair fire escapes with platforms close to windows. Because of the frame like appearance of these ladders they came to be known as 'skeleton escapes'. (Wermiel 2003, 261) By the 1900's almost all cities in the USA had some form of building code requiring fire escapes. (Wermiel 2003, 263)

Figure 03: *"Ornamental fire escape, One Hanover Square, New York City." (Wermiel 2003, 273)*

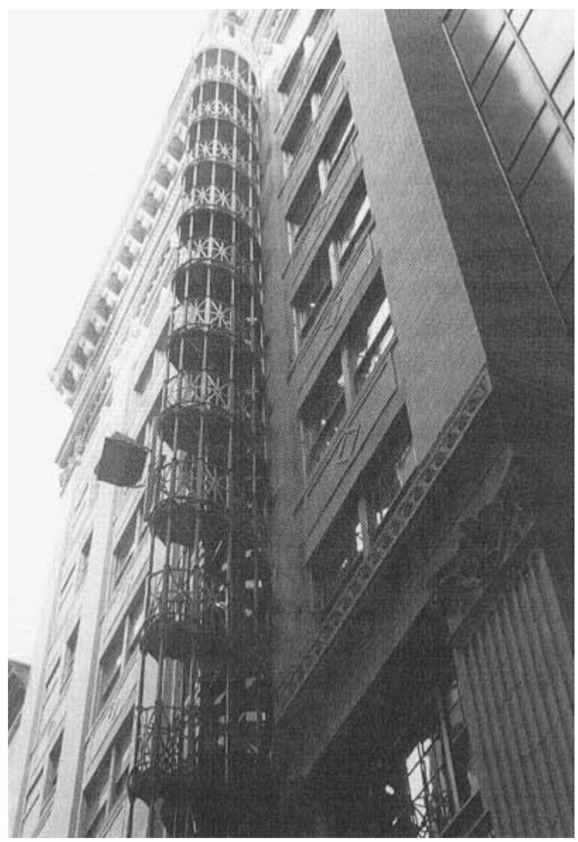

Figure 04: *"Spiral fire escape on a Boston office builidng, 31 State Street." (Wermiel 2003, 274)*

It was around the 1880's that automatic sprinkler systems were designed. They were originally developed to protect against fires in textile mills in New England. These mills had very combustible ceiling structures and as such the sprinklers were designed to direct half of the water upward to protect the ceiling with the remainder of the water being reflected downward onto the fire. This system worked so well that it remained unchanged until 1950 when the spray sprinkler was developed for fires in warehouses. The spray sprinkler directed all water down onto the fire and was accepted as the standard sprinkler in the USA in 1953 replacing the older style sprinkler. (Yao 1997, 93-94)

The New York Triangle Shirtwaist fire in 1911 was the event that prompted a more in depth review of high-rise fire safety. A study of the ten storey building found that it did not comply with fire escape standards at the time and that the current standards were inadequate for a high-rise fire. The experts agreed that the 'skeleton' fire escape was not the solution and began to establish guidelines for emergency exits inside the building. In 1915 tougher standards for outside stairs were introduced, and in 1916 standards for internal stairs were introduced. The conditions under which internal stairs were required, depending on height and whether buildings were sprinkled were also established. (Wermiel 2003, 261; Krohe 2006; Hill 2003, 102)

By 1923 no outside exits were accepted in the United States of America. Following on from these provisions, the 1949 national building code of the United States of America called for stairs to be accessed by doors rather than windows and constructed to the same standard as internal stairs. (Wermiel 2003, 261)

After World War 2 a series of *Post War Building Studies* was commissioned in Great Britain. Commencing in 1941 these building studies covered everything from plumbing to the lighting of office buildings. In 1946 part one of Fire Grading of Buildings was published and in 1952 parts two to four were published. These documents did not constitute regulations but were widely used as design standards. They explained the reasoning behind compartment sizing, sprinklers, storey separation, stair widths, fire-resistant construction, building separations and openings, protection of steel work, hydrant systems and the science behind these requirements. (A joint committee of the

Building Research Board of the Department of Scientific and Industrial Research and of the Fire Offices' Committee 1946; 1952a; 1952b)

It is through these studies that the concept of floor to floor separation originated to stop the spread of fire vertically. “A reasonable degree of protection could be obtained by providing at least 3 ft. of construction (of which at least 2 ft. should be above floor level) of the same grade of fire resistance as the walls … This would, in addition, provide the pitching for firemen’s ladders and for emergency rescue.” (A joint committee of the Building Research Board of the Department of Scientific and Industrial Research and of the Fire Offices' Committee 1946, 64)

Before 1970 there were no specific tall codes in the USA, although in other parts of the world such as Hong Kong legislation dating back to 1955 had been written in response to the condition of buildings that are occupied above the height of fire fighting ladders. (Public Works Department 1955) The intent of these codes was to protect occupants, when fires could not be fought from the outside. (Quiter 2006)

2.2 The Queensland and greater Australian Experience

Prior to the 1975 Building Act in Queensland each local authority had its own building regulations. The Building Act was introduced primarily to standardise these regulations to make it easier for architects, engineers and builders working across local authority boundaries. The technical aspects of the Building Act originated from the *Australian Model Uniform Building Code* developed by the Interstate Standing Committee on Uniform Building Regulations. This committee latter became the Australian Uniform Building Regulations Co-ordinating Council before becoming the Australian Building Codes Board. (de Veer 2007)

The motivation to introduce the Building Act at this time in Queensland was a result of a number of fires both locally and internationally; in 1970 one hundred and forty-six people died in the Cinq September Club in Saint-Laurent-du-Point, France, in 1971 one hundred and sixty-six people died in the Daeyongak Hotel in Seoul, South Korea, in 1972 one hundred and eighteen people died in a nightclub on the seventh floor of the Sennichi Department Store in Osaka, Japan, (Arnold 2005,

16) in 1973 "fifteen people died in a fire-bombing incident at the 'Whisky Au Go-Go' Nightclub in Brisbane." (*Brisbane, Qld: Fire* 2006) and in 1974 two hundred and twenty-seven people died in the twenty-five story Joelma Building in Sao Paulo, Brazil. (Arnold 2005, 16)

The Building Act 1975 came into force on the first of April 1976. It was a prescriptive code and in the absence of performance standards a variations sub committee was set up in order to facilitate the approval of built or proposed buildings that did not comply with the Act. Although this subcommittee was a forerunner of a performance based code it was not truly performance based as it judged buildings on equivalence rather than meeting standard. (de Veer 2007)

In 1987 Alan Parnell a British architect visited Australia as part of an Institution of Fire Engineers building regulations convention and publicly criticised Australia's Building regulations. At this time the United Kingdom was going through a process of developing an alternative code based on objectives and functional statements. Parnell described Australia's building regulations as "inflexible and immensely detailed, which in most cases, did not deliver the level of expectations of the Australian community." This criticism started a process which led to the introduction of the Building Code of Australia. (Odgers 2002, 10)

In 1990 the first issue of the Building Code of Australia was published as a national uniform building code. Although it contained some performance based statements it was predominantly prescriptive and was not nationally enacted. (Odgers 2002, 11) By 1996 the Building Code of Australia was recognised and legislated nationally and it had been reformed to present a duality of prescriptive and performance based requirements. (Worcester Polytechnic Institute 2000) This gives architects and engineers the choice to either follow a prescriptive set of rules or to meet a required level of safety via other means. (de Veer 2007; Poon and O'Meagher 2007) "The alternative approach offers a high degree of design flexibility, is safer than prescription, is more cost effective and, above all these, promotes teamwork amongst all parties involved in the fire safety design process." (Odgers 2002, 31) This follows the United Kingdom in 1985 and was followed by New Zealand in 1992. (Worcester Polytechnic Institute 2000; Young, Wade and Fleischmann 2004, 1/12) "In a performance-based code environment, performance fire safety requirements, rather than prescriptive requirements, are specified. The performance-based approach allows for flexibility in design that, if applied appropriately, can lead to lower construction costs without lowering the level of safety." (Young et al. 2004, 1/12)

As Stollard and Abrahams discuss, complete fire safety in a building is unachievable, and the risks associated with building only come to one's attention when a serious or fatal fire occurs. Legislation is therefore reactionary, coming about because of public outcry, which in turn sets the minimum standard to which buildings are to be built. (1999, 1) "It can be shown that not only is legislation enacted in response to disaster, but also that changes in building forms and technologies normally occur in response to disaster."(Stollard and Abrahams 1999, 17)

"Regulation is only in place where there is market failure." (de Veer 2007) the BCA is the minimum requirement necessary, not necessarily best practice. It has demands placed on it from industry, builders, government, designers and ultimately the users to set a minimum standard of health, equality, safety and responsible design. The BCA was introduced due to industry demand as part of a micro economic reform to consolidate state expectations so that every building authority in the country administers the same legislation. This allows certifiers, designers, builders and engineers to work nationally with ease. The only remaining differences between councils are planning schemes and some state specific clauses. (de Veer 2007)

3.0 Fire Safety Regulations for Tall Buildings

The primary aim of all fire safety regulations are to ensure "A building is … provided with means of evacuation which allow occupants time to evacuate safely without being overcome by the effects of an emergency" (Australian Building Codes Board 2006a) This is primarily achieved through the evacuation of a building using its fire escape stairs and the design of buildings so that occupants are within a particular travel distance in the event that there is a fire.

3.1 Building evacuation

The safe evacuation of the occupants of a building is one of the fundamental objectives of the provision of fire regulation in tall buildings. Buildings should be designed to facilitate the escape of people during a fire. Safe escape from fire can be provided by simple getting the occupants out of the building faster than the speed at which the smoke spreads through the building. Safe escape can be achieved through simple, short, circulation and escape routes. (Stollard and Abrahams 1999, 49) "Studies on eight vertical escape methods, including rescue by helicopter, conclude that the fire brigade (fire fighter) elevator is ideal as a supplement to primary exit staircases and especially useful for egress by the disabled." (*Fire Safety in Tall Buildings* 1992, 53) In both Australia and Hong Kong there is a requirement for emergency lifts to service every floor of the building. Other than to facilitate the ingress of firefighters its main purpose is to allow for the escape of the disabled and injured. Another approach to the egress of injured and disabled is to provide a refuge within the stairwell. This has been legislated in Scotland and Hong Kong and is advised in England and Wales. (Johnson 2005, 216)

Full Evacuation

Within the literature on designing escape routes out of a tall building there has been a shift in approach from designing a building where it is evacuated in stages, to designing it to handle a full evacuation. (Lane and Lamont 2005, 4) Currently stairwell capacity in the United States is calculated assuming that only one floor will be evacuated at a time. (Krohe 2006) The reasoning for this is that it was assumed that fires could be contained within a single fire compartment and evacuation would therefore be staged to evacuate the fire effected floor and then the floor above and below it before the rest of the building. (Travi 2001, 38) “This mode of evacuation forms the basic underlying philosophy of egress in high-rise structures and hospitals today. The goal is to relocate occupants that may be near the point of origin of an incident to an area that is otherwise protected.” (CTBUH 2004, 16)

Staged evacuation is common practice in Australia as well as the rest of the world and is the best form of evacuation for small common fires. (CTBUH 2004, 10; de Veer 2007) Recently this ‘protect-in-place’, staged evacuation approach has been questioned in the wake of the World Trade Centre incident and the increase in perceived risk of terrorism. (Lane and Lamont 2005; Vries 2006; Krohe 2006; *Tall buildings and safety: Five years since 9/11* 2006; *Fire Safety in Tall Buildings* 1992; *High-Rise Manual: Typology and design, construction and technology* 2002)

> *For the first time in history, the need to perform total building evacuation in high-rise buildings became more of a reality. Traditional building perils such as fire, seismic events and windstorms must now include acts of terrorism, or hostile acts. The type of actions to consider might include: incendiary fires with multiple ignition points on multiple floors; explosives detonation either inside the building or on the exterior of the building; release of a toxic material (chemical, biological or radiological weapon) that may spread to occupied areas of the building. Events occurring in adjacent structures or buildings are also potential evacuation triggering events for surrounding structures. (CTBUH 2004, 12)*

Increased interest in full evacuation has extended to interest in various methods of providing areas of refuge, the use of lifts in evacuation and the training of occupants in buildings. (CTBUH 2004)

Refuge Floors

The model of refuge floors and escape presented in *Fire Safety in Tall Buildings* is one where the occupants are instructed to proceed down the stairs to the nearest refuge floor and then escape via stairs or the lift. “Once people reach a refuge floor and see fire fighters there, they will be psychologically relieved and more confident of their personal safety. (*Fire Safety in Tall Buildings* 1992, 53). The Refuge floor serves as a sub base for fire fighters and a relief area for occupants escaping the building. “The refuge floor must therefore be isolated by construction features to prevent smoke and hot gasses from migrating to floors above and below it.” (*Fire Safety in Tall Buildings* 1992, 49) In staged evacuation it is also common to evacuate the affected floors to the refuge floor rather than to the ground. (CTBUH 2004, 11)

Refuge floors have been legislated in Hong Kong since 1995 (Building Authority 1996, 29) The refuge floor is considered part of the exit route, “it acts as a safe place for a short rest before people continue to escape downwards as it is difficult for most people to walk down a tall building without pausing.” (Lo and Will 1997, 739) it allows for people to transfer to an alternative staircase if they encounter smoke or wait for rescue if all stairs become inaccessible. The refuge floor also provides a sub-base for fire fighting and directing people out of the building. (Lo and Will 1997, 739)

Under the 1996 *Code of Practice for the Provision of Means of Escape in Case of Fire* there is a provision for a refuge floor every twenty to twenty-five floors. This is based upon travel speeds and the fact that most occupants will experience fatigue after descending for more than five minutes. (Lo and Will 1997, 739) In a forty-seven storey building, with a floor to floor height of four metres and a population of three thousand, three hundred people, seventy persons per floor, it can be expected that in the first five minutes twenty precent of the building will be evacuated using two 1200mm staircases, with the entire building being evacuated in a total twenty-five minutes. (CTBUH 2004, 35) The legislated requirement for a refuge floor every twenty to twenty-five storeys in Hong Kong accounts for variances in floor to floor heights between different buildings and the varying speeds of occupants. In an evacuation using the example outlined above, a refuge floor at the twenty-fifth floor would halve the total evacuation time of occupants exiting to the refuge floor or to ground.

Lo and Will discuss the implications of refuge floors in their article and state that the introduction of a refuge floor may slow the evacuation of a building but is very important psychologically. The refuge floor serves to assist in occupants orientating themselves, it gives them reassurance with the presence of the fire department and gaining control over their situation as the refuge floor gives the occupant an opportunity to choose whether to continue their descent or wait for the assistance of the fire services. Because of the reduction of the stress of the occupants it is also much easier for fire fighters to manage crowd movement with respect to lift evacuation. To reinforce this psychological benefit Lo and Will stress the importance of fire drills. (1997, 741)

Although refuge floors are best practice in the design of very tall buildings they are not required in Australia as they are above the minimum standard of fire safety as decided by the Australian Building Codes Board. (de Veer 2007)

Emergency Lifts

Within Australia, Hong Kong and others around the world there is a requirement for fire-fighter's lifts to facilitate faster evacuation and the evacuation of the elderly, disabled, injured and children under the supervision of the fire service. Because of these functional requirements lift manufactures have developed lift control software which changes the behaviour of the lift depending on the scenario;

- Earthquake – where the lift car is slowed to the nearest landing
- Fire – where the lift car is returned to the 'ground' lobby and is then controlled by fire-fighters
- Threat – where the lifts fill to capacity and descend directly to ground
- Normal.

This is particularly useful in a non-fire situation as the system runs automatically and very efficiently but in fire modes when the car is controlled by firemen the lifts travel at maximum power, neglecting comfort and engage a door nudging option where when the lift is nearing capacity to aid in crowd control and stop overcrowding. Although it is advantageous to engage the use of lifts in evacuation, in a fifty storey building "a viable elevator evacuation time is around 20-30 minuites. Using both elevators and stairs, an evacuation time below 20 minutes can be expected."(Barlund, Kattainen, Makela and Siikonen 2005) Reinforcing the common practice of escape via stairwells.(Barlund et al. 2005)

3.2 Implications of the World Trade Centre Attack

The issue of high-rise safety is one which is being widely discussed at the moment as the implications of the World Trade Centre disaster are being realised. Early last year the USA National Institute of Standards and Technology produced a report on the outcomes and recommendations of an investigation into the collapse of the buildings. The recommendations are intended for buildings over 20 stories and aim to improve "the way buildings are designed, constructed, maintained, and used and in evacuation and emergency response procedures." (Assessing the NIST World Trade Center Investigation 2006, 64) Recommendations cover the categories; improving building design, construction, maintenance, evacuation and emergency responses. (NIST reports on WTC building and fire safety to House Science Committee 2006, 64) Many of the recommendations in the report are beyond the ability of society to meet at this time such as the prevention of progressive collapse without explaining what factors need to be considered in order to do this. (Assessing the NIST World Trade Center Investigation 2006, 20) The recommendations have also been criticised for having a multi-hazardous approach i.e. designing a building to withstand a fire and hurricane at once (Schulte 2005) and for approaching the complex issue of terrorism as you would slip resistance.(Post 2006)

But it has not only been the World Trade Centre incident that has kept high-rise fire safety a current issue. In the past three years there have been two tall building fires in Chicago, one in Madrid in 2005 and one in Venezuela, 2004. The Chicago and Madrid fires were in non sprinkled buildings and in the Venezuela fire the sprinklers were inoperable. (Quiter 2006) Tall buildings are here to stay - the price of land demands it. Therefore the question is now how can buildings be made safer? How can tall buildings be designed so that they will withstand bombs, airplanes and missiles? How can they be built so that they withstand major fires and protect people from the health side effects introduced into the environment? (Krohe 2006, 5)

3.3 Building envelope

There are five tactics available to the architect to fulfil their obligations for safety of occupants and protection of property. These are; prevention, communication, escape, containment and extinguishment. (Stollard and Abrahams 1999, 15) The most influential of these tactics to the building form are escape and containment.

Containment

Containment provides both life safety and protection of property making it the relevant measure of fire protection for insurance companies. Containment of the fire can be placed into four categories; structural protection, compartmentalisation, envelope protection and smoke control. (Stollard and Abrahams 1999, 68-69)

Structural Protection

Structural protection refers to the materiality of structures within tall buildings. This is often achieved naturally through adopting the prescribed 'Fire Resistance Levels' of fire compartments specified in the Building Code of Australia. A Fire compartment is defined as "any part of a building separated from the remainder by barriers to fire such as walls and/or floors having an appropriate resistance to the spread of fire with any openings adequately protected" (Australian Building Codes Board 2006b)

Building Envelope

The envelope of a building forms part of the fire compartment and therefore also has to stop the spread of fire into another compartment. "Fire-resistive compartmentation has been stressed within and between individual floors. Performance of construction details at floor perimeters, however, has not been stressed as much in fire resistive design. In these cases, curtain-wall constructions are used frequently, and fires have occasionally spread upward in certain, spectacular cases." (*Fire Safety in Tall Buildings* 1992, 10) The cases used as an example to illustrate this point are the Fist

Interstate Bank fire in Los Angeles, California fire of 1988 and the Las Vegas Hilton fire of 1981.(*Fire Safety in Tall Buildings* 1992, 7, 10) Some solutions to the problem of glazed facades and double skin facades are the integrations of balustrades, cantilevered slabs and specialized sprinkler systems into the façade construction. (*High-Rise Manual: Typology and design, construction and technology* 2002, 201)

Smoke Control

Smoke control is vital for the survival of occupants in a building fire "in many cases, fires kill people by asphyxiation or poisoning through the inhalation of smoke or toxic gasses." (Alexander 1993, 476) Traditional methods of smoke control include; barriers, smoke vents, and smoke shafts, but the effectiveness of these methods are limited to the proximity to the fire and leakages. (*Fire Safety in Tall Buildings* 1992, 24) It is because of this that smoke control is generally managed through HVAC systems. (*High-Rise Manual: Typology and design, construction and technology* 2002, 198; *Fire engineering design guide : report of a Study Group of the New Zealand Structural Engineering Society and the New Zealand Fire Protection Association : endorsed by the Society of Fire Protection Engineers, New Zealand Chapter* 1994)

3.4 Retrofitting Buildings

New codes which have come into place in the USA following September 11 require increased fire ratings for structure, increased stair widths, photo luminescent markings, similar to glow in the dark stickers (Vries 2006; Krohe 2006) One of the problems arising from the ever improving standards and codes is how to deal with older buildings. There are no clear regulations in the USA when it comes to retrofitting. (Quiter 2006) Buildings designed to older codes when judged by current standards may be "considered to have 'sub-standard' fire safety protection" (Lo, Hu, Liu and Yuen 2005, 255)

In Queensland the 1975 Building Act outlines the parameters under which a building certifier decides whether the fire services must be upgraded in the process of renovating a building. When alterations represent more than half of the total volume of the building "the building development approval may include a condition that all, or a stated part, of the existing building or structure must comply with all or a stated part of the building assessment provisions as if it were a new building or structure." (*Building Act 1975* 2006, 57; Moran 2007) Resultantly if a building does not undergo major renovations the fire services would not be upgraded. (de Veer 2007)

The predominant question asked by Cobin in *Building regulation, market alternatives, and allodial policy* is "Does government regulation of building safety actually produce building safety improvements that justify its cost? … Is safety actually improved by it?" (1997, 14) Some of the reasons that the regulation of building is advocated, is to protect the public from market failure, negative externalities and to ensure the protection of public health, safety and welfare. This has led to an increase in social and individual costs and has moved disputes over damages away from individual retribution and into the legal realm. (Cobin 1997, 13-14; Colwell and Yavas 1992, 513) This has led to a study of risk, tradeoffs, information, politics and the question of whether regulation is an effective solution, or even a desirable placebo treatment to alleviate public fear.

"The paramount concern of government regulation is to enhance public safety by reducing social risks." (Cobin 1997, 14) Regulation usually increases safety but most often at a high cost or in an inefficient way; this is due to imperfect information which leads to market failures resulting in public outcry. (Cobin 1997, 14-15) Polls say that the public supports regulations despite the added cost to society. (Cobin 1997, 16) "… the public errantly perceives it[s] [safety] to be low-cost when it is at the expense of firms via tougher regulations" (Cobin 1997, 22) Secondary to regulation safety is achieved through information and higher quality of life which reduces market imperfections. Cobin suggests that the public perception that improvements in regulations are improving safety alleviates unease. This influences the risks that the public takes, "better informed people are more likely to behave safely." (Cobin 1997, 20)

This is most evident in Japan where the predominant focus of fire safety is people, "As the global source of cutting-edge electronic equipment, it may seem surprising that the Japanese rely more on people than technology when it comes to fire safety, but training remains key to the Tokyo Fire Department." (Laitinen 2002) Tokyo has a very low fire rate, most of its buildings are five to seven stories high and climbing. Within large buildings or buildings that contain 2000 people or more, workplace managers are required to form private fire brigades. These building fire protection managers and their brigades are trained to be able to deal with disasters and fires. They conduct fire drills annually or more frequently depending on the occupation and there is also a national fire drill focusing on earthquake preparedness every year. (Laitinen 2002)

In Australia there is a greater importance placed on the performance of buildings under fire conditions than the performance of tenants. Although as part of the *Fire and Rescue Service Act* there is a requirement that every building, excluding detached housing and terrace houses, is to have a fire safety management plan which addresses the number of occupants, fire safety installations maintenance, training of occupants, evacuation of the building including occupants with a physical or intellectual disability and fire management and protection. (*Fire and Rescue Service Act* 1990, 62) Required fire evacuation plans, fire drills, maintenance, emergency lighting, exit signs, fire extinguishers, early warning and intercommunication systems all affect the response of occupants in a building fire. (de Veer 2007)

4.0 Fire and its impact on the form of buildings

Tall buildings generally fall into two categories, the first one being where services are concealed i.e. the central core or atrium core and the second where services are revealed i.e. the end core and split core. (Yeang 2000)

The concealed approach is the most common in the design of tall buildings and as a result has formed the typical typology of a tall tower until recently. Originally with the beginnings of skyscrapers in New York and Chicago in the early nineteenth century a central core has been used to maximise the economy of the floor plate with respect to maximum travel distances, structural limitations and the desire for an open floor plan. (Peters 1991)

The second approach to incorporating legislated fire-isolated stairwells and associated services into tall design is to move them to the periphery of the building and provide the client with flexible floor space. (Yeang 2000, 15) This is integral to the philosophy of the office of Richard Rogers;

> *For functional reasons we always create clear zoning between servant and served spaces within a building. We often separate and juxtapose the services with the mass of the building; in practical terms the part of the building which is inhabited has a long life, whereas the technical services have a short life and therefore need to be accessible for change and maintenance. By separating the mechanical services, lifts, electrics, fluids and air-conditioning from the rest of the building, inevitable technical developments can be incorporated where they are most needed to extend the life of usable core space. The articulation of the services and core building creates a clear three-dimensional language, a dialogue between served and servant spaces and a means of creating flexible floor space … and allow for flexible tenancies that respond to the changing demands of the office market*. (Richard Rogers Partnership 2005b)

This is evident in the design of 112 Leadenhall Street, London, this building uses an end core which is clearly expressed on the northern side of the building. This support core contains the lifts, risers and toilets creating a foyer at the entrance to each floor. The fire escape staircases are separate to this and are at the end of the bulk of the building prior to bridging to the support core.

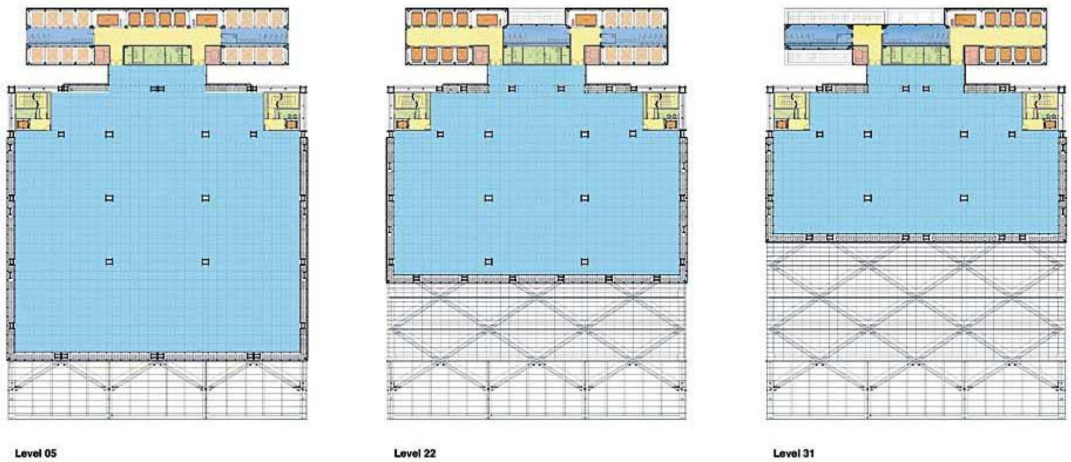

Figure 05: *112 Leadenhall Street, London (Richard Rogers Partnership 2005a)*

This approach was used by Louis Kahn in the Richards Medical Laboratories, Philadelphia, 1961, "provisions for environmental services give an immediately striking profile in both plan and elevation." (Banham 1984, 246) Kahn placed all of the pipes and services outside the building and at least one of these towers on each building was a fire egress stair, originally intended to be circular the stairs ended up being square and only discernable from the external services in size. (Banham 1984, 249-252)

The decision on how to satisfy fire regulations is based on the economy of building where, "minimal external wall thickness, minimum vertical support size, minimum horizontal support thickness, minimum vertical circulation/service core area [and] minimum floor-to-floor height" (Yeang 1991, 114) are the drivers of design. Both the concealed and revealed approaches meet the requirements of the appropriate buildings codes and market demands.

4.1 Atrium buildings, ventilated facades and clear glass buildings

“Fire-resistive compartmentation has been stressed within and between individual floors. Performance of construction details at floor perimeters, however, has not been stressed as much in fire resistive design. In these cases, curtain-wall constructions are used frequently, and fires have occasionally spread upward in certain, spectacular cases.” (*Fire Safety in Tall Buildings* 1992, 10) The cases used as an example to illustrate this point are the Fist Interstate Bank fire in Los Angeles, California fire of 1988 and the Las Vegas Hilton fire of 1981.(*Fire Safety in Tall Buildings* 1992, 7, 10)

The integration of environmental design initiatives is becoming increasingly frequent and necessary in the design of tall buildings. (Tan 2007) However with the increased use of atria and natural ventilation in tall buildings fire engineering has become prevalent in the provision of building specific design solutions that meet an acceptable level of personal safety for occupants and building protection for insurers. This is very evident in the design outcomes of 30 Mary Street in London, otherwise known as the Gherkin and the Deutsche Bank building.

30 St Mary Axe is a fully glazed, naturally ventilated office building containing eighteen spiralling atrium light wells that maximise the penetration of daylight and interconnectivity between floors. Fire engineering allowed for the “natural ventilation of the atria, integrated with routine environmental vents [and the] simplification of fire-fighting shaft smoke ventilation with [a] space-saving natural system.” (Ferguson 2007) Arup Fire collaborated with Foster + Partners from sketch design through to construction administration allowing the benefits of a holistic fire safety approach to be integrated into the design of the building.

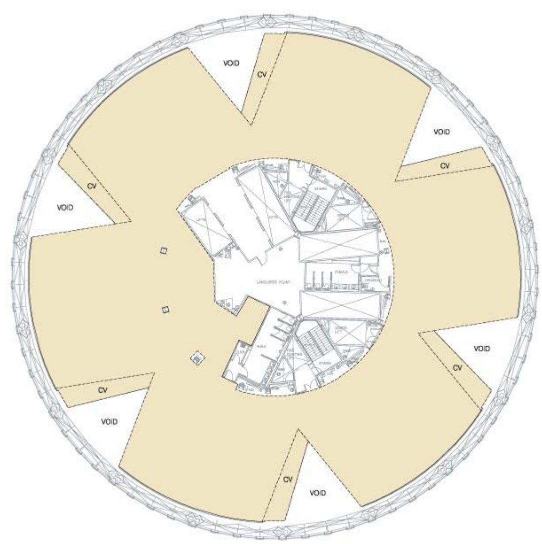

Figure 06: *Level 20 plan of 30 St Mary Axe (Accommodation: Floor Plans 2005)*

Figure 07: *(Deutsche Bank Place 2007)*

Deutsche Bank Place is another atrium building designed by Foster + Partners. Contra to traditional office design, an atrium separates the core containing fire stairs, lifts and all building services from the office floor plate. (Bressi 2005) "According to surveys, tenants need thirty percent less floor area than in an ordinary building with a central service core because of the higher efficiency of space." (Deutsche Bank Place 2007) The advantages achieved through opting for a fire engineered performance based solution in this building are as follows.

- *Planning strategies to enable inter-connecting tenant stairs to be opened over consecutive floors …*
- *Tenancy layout options were enhanced … due to the flexibility of egress travel distances being able to exceed 40 metres…*
- *Atrium bounding construction designed on a performance basis thereby eliminating the need for wetting sprinklers on the sides of the atrium glazing… smoke spilling into the atrium managed by a single exhaust fan linked with zone pressurization and sufficient time for evacuation from the uppermost floors...*
- *The smoke spilling into atrium is managed by the installed exhaust systems, thereby enabling the atrium to be used as a smoke relief path. (Bressi 2005)*

5.0 Case Studies

The case studies chosen for this study all fall under the tall building typology of concealed services as defined in the preceding chapter. This is the most common of tall building typologies and as a result information about these building is more readily accessible. The second reason for this categorisation is that in order to make justifiable comparisons between buildings built in different locations and at different times they must have some commonality.

Two case studies have been chosen, one from Brisbane and the other from Hong Kong within three time periods; prior to 1975 when the Queensland Building Act was introduced and the 1976 Codes of practice: Wind effects and Provision of means of escape in case of fire and allied requirements in Hong Kong; between 1975 and 1996 and after 1996 under the performance based Building Code of Australia and codes of practices introduced in 1995 in Hong Kong.

The significance of comparing these six examples is that it shows the change in building form as a result of the development of fire codes and the difference in buildings internationally as a result of different legislation. The selected buildings chosen for further investigation are

- Alexandra House built in 1976 in Hong Kong
- 294 Adelaide Street built in 1972 in Brisbane
- Shangri-La Hotel built in 1991 in Hong Kong
- Waterfront Place built in 1989 in Brisbane
- Harbourfront Landmark built in 2001 in Hong Kong and
- Brisbane Square built in 2005/06 in Brisbane

These case studies are to be analysed against the legislation applicable to them at the time of their design and construction. The stairs, emergency lifts, refuge spaces, emergency vehicle access and fire separation are the aspects of tall building design that are most affected by legislation and have the greatest impact on the functionality of the building in the event of a fire.

The way the architect decides to treat and locate fire services will impact on the design outcome. "The … vertical component and key element in designing the service core is the staircases. Their location, as a required means of egress, is often one of the decisive form-givers in any major building." (Yeang 2000, 47)

5.1 Case Study Comparison

	Alexandra House	294 Adelaide Street	Shangri-La Hotel	Waterfront Place	Harbourfront Landmark	Brisbane Square
Year	1976	1972	1991	1989	2001	2006
Location	Hong Kong	Brisbane	Hong Kong	Brisbane	Hong Kong	Brisbane
Occupancy	Office	Office	Hotel/Office	Office	Residential	Office
Height	124m	82m	213m	162m	233m	151m
Storeys	36	23	57	40	70	38
Basements	2	1	2	1	2	1
Fire Stairs	3	2	3	2	9	2
Emergency Lifts	1	0	2	2	4	?
Sprinklered	Y	N	Y	Y	Y	Y
Stairwells pressurised	Y	N	Y	Y	N	Y
Refuge	1 Floor	-	-	-	2 Floors	-

5.2 *Alexandra House - 1976*

Alexandra House designed by Palmer and Turner Architects & Engineers was constructed in 1976. Designed under; the Code of practice on provision or means of escape in case of fire and allied requirements, 1959 and the Codes of practice: Minimum fire service installations and equipment and Inspection and testing of installations and equipment, 1964 this building embodies a large amount of legislation.

In 1964 control over the design of buildings changed from lease control to ordinance control. As there is no land ownership in Hong Kong the conditions on the lease of land regulated much of the building until 1964 when the Building Ordinance was revised to include and consolidate these conditions. This resulted in smaller buildings with a podium and tower form. Designers were permitted to have one hundred percent site coverage up to fifteen meters as long as they submitted site coverage calculations with their building applications. (Howes 2007)

Figure 08: *Alexandra House, photo by author*

Stairs

Alexandra house contains three major staircases servicing every floor of the building. At the ground floor stairs one and two exit via a fire isolated corridor to Des Voeux Road Central and stair three exits via a fire isolated corridor to Charter Street. This is compliant with the Code of practice on provision or means of escape in case of fire and allied requirements, 1959 which required that

"Every exit route shall lead directly to a street or to an open area ... Such access … shall not be closed with doors … unless such doors... are fitted with panic bolts." (1959, 6) The doors in these corridors are two inch solid core doors with panic bolts as indicated on the plan. (Palmer and Turner 1975)

The stairs from the basement levels shown in blue also exit directly onto the street and are physically separate to the stairs rising up the tower. The doors in these corridors are also fitted with panic bolts. (Public Works Department 1959, 6)

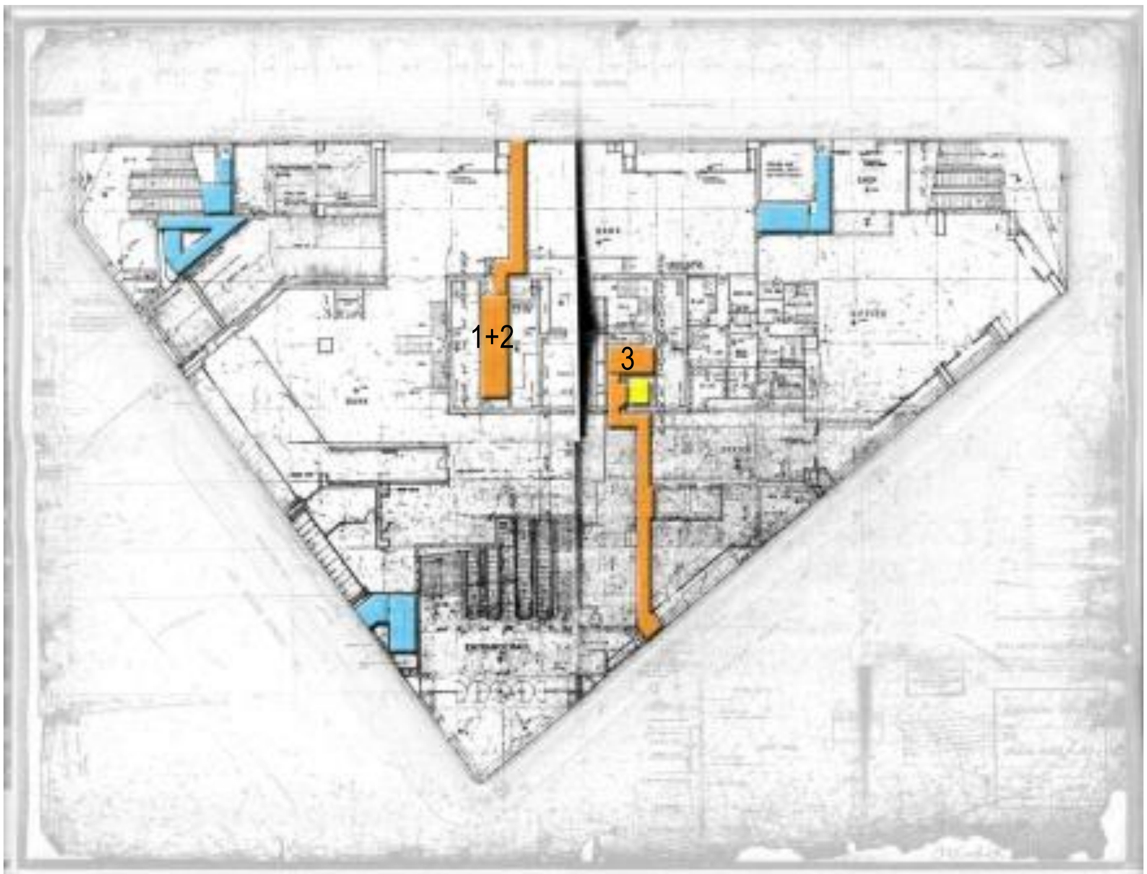

Figure 09: *Ground floor exit routes (Palmer and Turner 1982)*

As part of the submission the calculations of numbers of exit routes are provided in the set of drawings. These calculations are based on the expected population in the building with respect to occupation. The required number of exits above the ground floor is two but three are provided. The basement follows a similar pattern where, two stairs are required and four are provided. (Palmer and Turner 1977b, 6; Public Works Department 1959)

As Alexandra House is an open plan office building and does not have a balcony approach to an exit the standard 36.5m to an escape applies. (Public Works Department 1959)

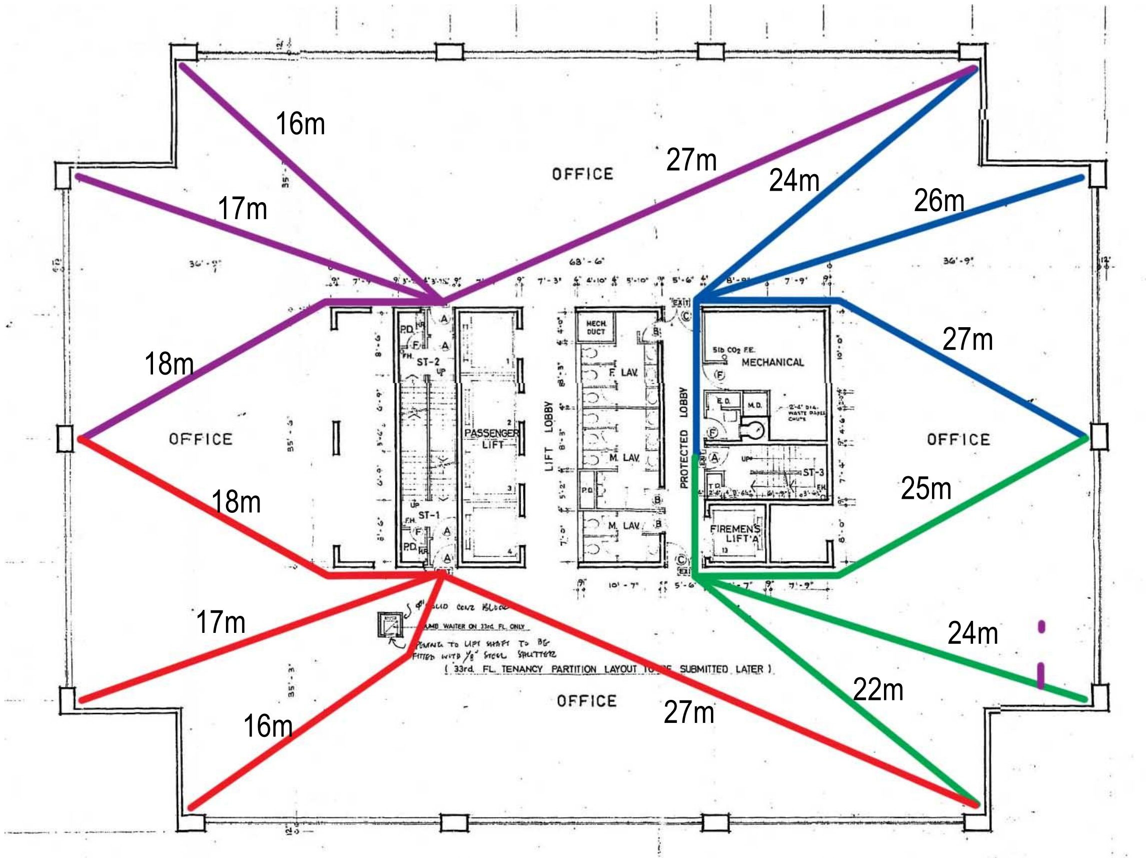

Figure 10: *Travel distances (Palmer and Turner 1977a)*

This explains why there are three staircases in this building rather than the required two staircases. This is evidence of the legislation a direct impact on the form of the building by introducing a third stair. The architectural implications of the third stair are that it increases the size of the core and as a result reduces the efficiency of the floor plate.

The only way that a floor plate of this size could be achieved with the minimum two stairs would be to place the two stairs in the centre of the core. The problem with this solution is that once furniture, partitions and the like are put in the space the travel distance becomes larger than the maximum 36.5m meaning that the building is no longer compliant. Alternatively stair one/two could have been merged and arranged similarly to stair three with a protected lobby approach, but this would have increased the area required for the core reducing the rentable area of each floor.

There is a requirement under the 1959 Hong Kong *Code of practice on provision or means of escape in case of fire and allied requirements* which states that “The exit route from any room, flat or storey to any part of a staircase which serves a storey more than 100 feet above the level of the ground shall be through a lobby” and where is lobby is not open to the external air on at least two sides it must be a protected lobby. (1959, 13)

The exit to stairs one and two is via a small airlock which could classify as a “protected lobby” but is not labelled as such on the plans. The access to stair 3 is via a “protected lobby” which also services toilets, plant rooms and the fireman’s lift.

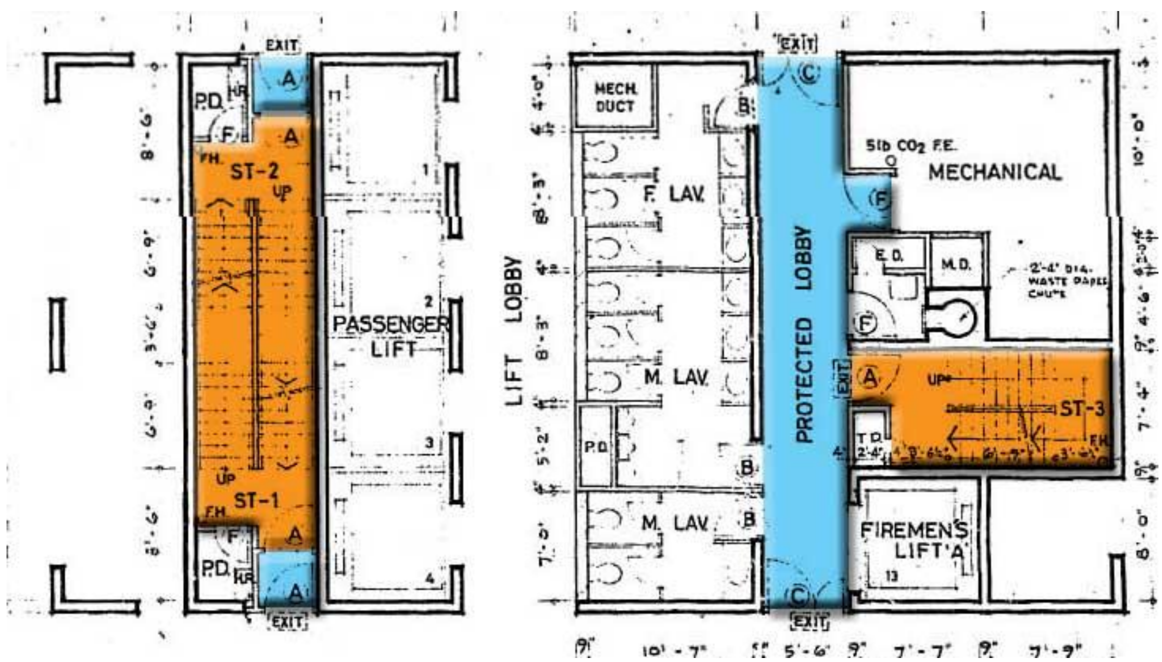

Figure 11: *Protected lobbies (Palmer and Turner 1977a)*

The design implications of the protected lobby are that it increases the size of the core of the building reducing its rentable floor area. However this airlock aids in the passive exclusion of smoke from the stairwells. This combined with the active smoke exclusion techniques of pressurisation in the stairwell aids in keeping the stairwells free of smoke longer. The protected lobby also acts as a place of refuge on each floor for the injured and disabled who are incapable of using the stairs.

The Code of practice on provision or means of escape in case of fire and allied requirements, 1959 states that “the access to the stairs shall be so arranged that each stair is approached from a different direction,” and that the stairs are to be arranged so that it is not necessary to pass through one staircase to reach another. (Public Works Department 1959, 14) The three major stair cases in this building are approached from three directions; from the north, south and east. While the protected lobby to stair three is accessed via the north and south, as stairs one and two, access to stair three itself is clearly from the east.

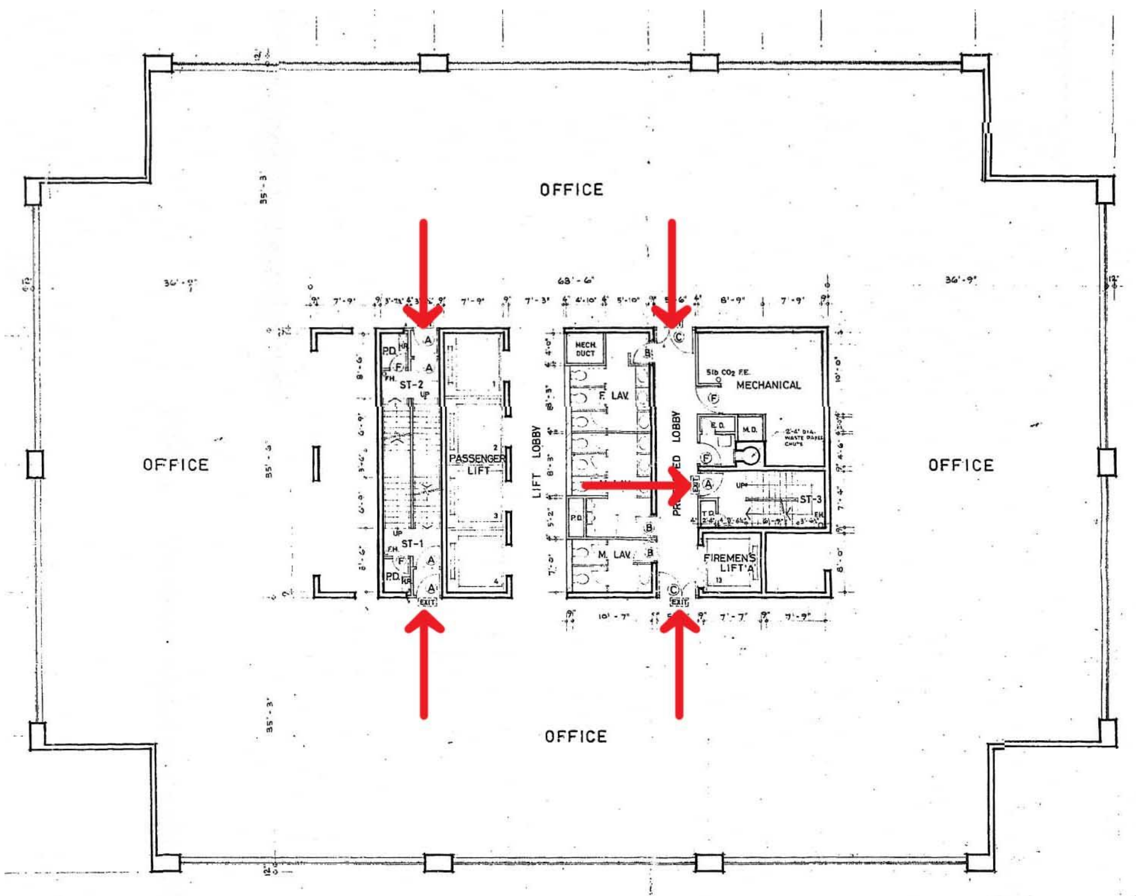

Figure 12: *Direction of stair approach (Palmer and Turner 1977a)*

Stairs one and two have used a scissor stair configuration in order to create a more efficient core. Through the process of stacking the two stairs and adding a wall to divide them both they are both are able to be autonomous. According to Robin Howes a Hong Kong building Surveyor and Fire engineering consultant, scissor stairs sharing a common landing were prevalent prior to 1959. Under the 1955 buildings ordinance stairs were required to be constructed of "fire resistant materials", but there is no mention of separation from the rest of the buildings meaning that if smoke enters the shaft it makes both staircases inaccessible in a fire.(Howes 2007; Public Works Department 1955, 20; Public Works Department 1959)

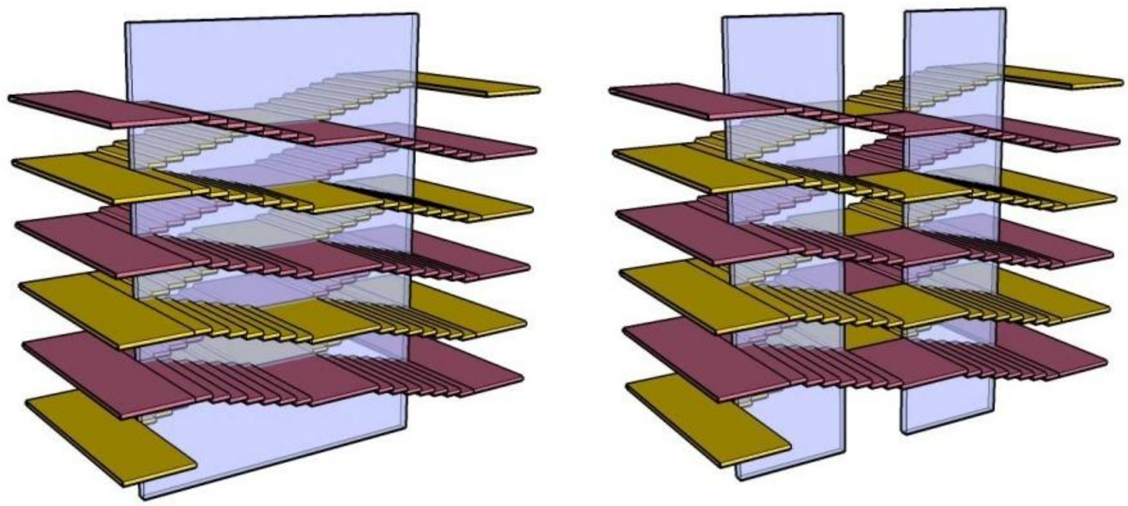

Figure 13: *Stair Study, by author*

Emergency Lifts

Alexandra House's emergency lift complies with all of the clauses relating to it; it is in a separate fire-resisting shaft, and it discharges in to a protected lobby on each floor. (Public Works Department 1964, 7) Interestingly it's smoke lobby doubles as a protected lobby for stair three.

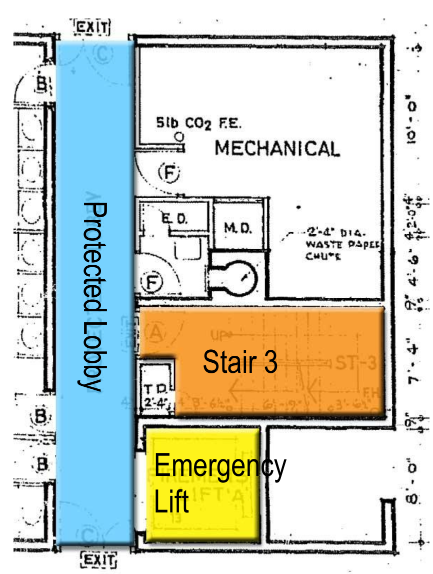

Figure 14: *Relationship between lobby, stair and emergency lift. (Palmer and Turner 1977a)*

Refuge Floor

The design of Alexandra House includes a refuge floor as notated on the plans on level fourteen. Under the 1959 *Code of practice on provision or means of escape in case of fire and allied requirements* and 1964 *Codes of practice: Minimum fire service installations and equipment and Inspection and testing of installations and equipment* there is no reference or requirement for a refuge floor. The requirement for refuge floors was not legislated in Hong Kong until the introduction of the 1995 *Code of practice for the provision of means of access for firefighting and rescue purposes. (1959; 1964; 1995)*

The incorporation of the relief floor is an example of best practice by the design team of this building, for population calculations this floor has been zoned as mechanical but at least fifty percent of the floor area is an open area of refuge. The points of interest that can be observed in the design of this level are; the stairs stop forcing escapees to exit into the open area before re-entering the stairwell and proceeding down the building; once in the open area escapees have access to all three stairwells and the emergency lift which is the only lift to service this floor and the floor is naturally ventilated through being open on two sides.

Another interesting feature of Alexandra House is the helipad on the roof. Although this is not strictly a fire safety feature of the building there is precedent for the rescue of occupants from burning buildings with helicopters. (*Fire Safety in Tall Buildings* 1992, 3-8)

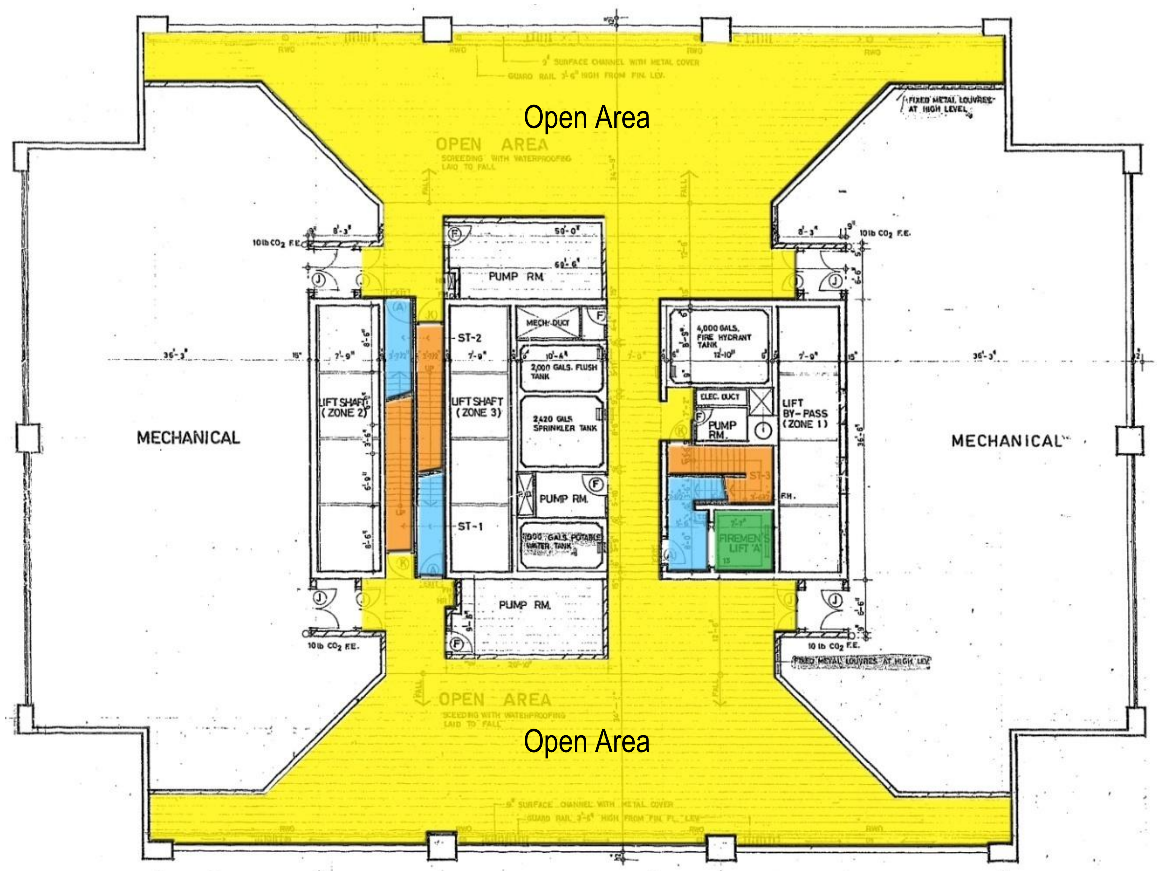

Figure 15: *Level 14 relief floor (Palmer and Turner 1976)*

Emergency Vehicle Access

The intended approach for emergency vehicles is via Charter Road, as this is where the fire service inlets are, fire control room and access to the emergency lift.

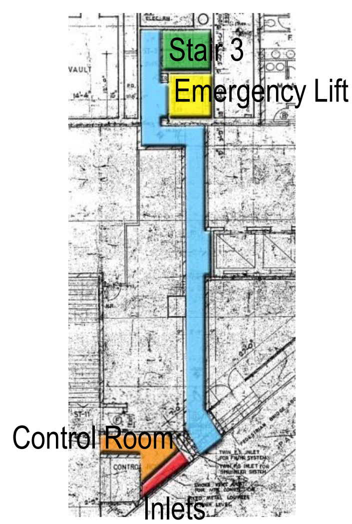

Figure 16: *Charter Road access (Palmer and Turner 1982)*

Fire separation

Other than a requirement for fire resistant construction there are no other requirements relating to fire separation such as spandrels or smoke baffles.

5.3 294 Adelaide Street - 1972

This example was chosen as it is a typical office building built in Brisbane prior to the introduction of the 1975 Building Act. The twenty three storey tower was designed by the firm Fulton Collin Boys Gilmour Trotter & Ptns.

Designed and built under chapter twenty-three of the Ordinances of Brisbane City Council, originally published in 1926, amended and reprinted in 1962, this building embodies the lax nature of the legislation.

Figure 17: *294 Adelaide Street, photo by author*

Stairs

The number of fire isolated stairways required for buildings over two stories under the *Ordinance of the Brisbane City Council* is one stair for every 100 squares (9.29m^2) of floor space, where only one fire isolated stairway is required an alternative stair must also be provided but this is not required to be fire isolated.(Chapter 23 1962, 42) Each floor of 294 Adelaide Street has an area of 62 squares (579m^2) meaning that two stairs are to be provided with one stair being fire isolated.

The design of this building has incorporated both of the necessary stairs in to a scissor stair arrangement ensuring that both of them are fire isolated from each other and the rest of the building. These escape stairs are not pressurised or naturally ventilated as this was not required under the 1962 Ordinance.

There are no travel distance requirements in the Ordinance, the location of stairways is determined by the vague phrase of “all stairways shall be as far apart as practicable, leading to separate exits.” (Chapter 23 1962, 42) The stairs in 294 Adelaide Street are in a scissor arrangement causing them to be close together adding to this they both discharge into the same foyer on the ground floor. Stair 1 also discharges in to the car park on the first floor may be how the architects could have been permitted to have both stairs leading to the same exit. Stair two continues into the basement, which is also served by as does stair three.

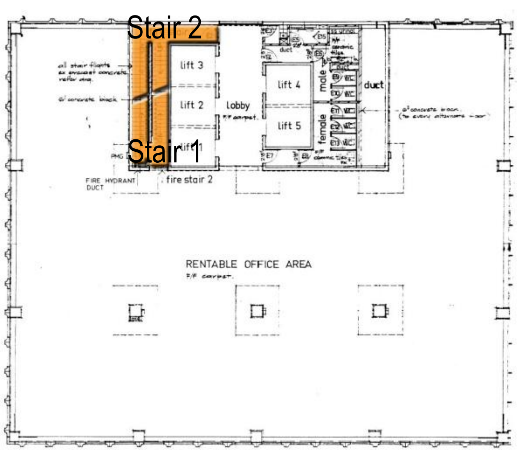

Figure 18: *Typical floor, stair location (Fulton Collin Boys Gilmour Trotter & Ptns 1972a)*

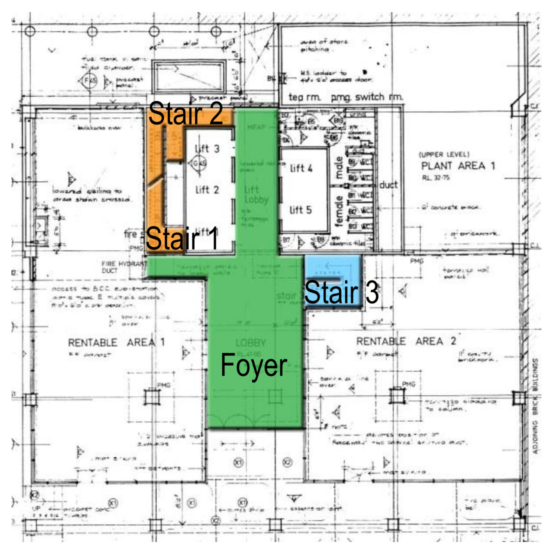

Figure 19: *Ground floor, combined escape route through foyer (Fulton Collin Boys Gilmour Trotter & Ptns 1972b)*

The design implications of the legislation requiring two stairwells with no consideration of maximum travel distances is that architects had a lot more flexibility in the planning of the building. The overall size of the building was therefore a result of the constraints of the site and technology rather than the safe evacuation of a building in the event of a fire.

Emergency Lifts

Emergency lifts were not required at this time and therefore none were provided. This building contains five standard lifts.

Refuge

No area for refuge was provided in this building.

Emergency Vehicle Access

There were no legislated requirements for emergency vehicle access in the *Ordinances of Brisbane City Council.* The pump room is located on the second level of car park but it has no emergency vehicle access. Access to this building is via Adelaide Street.

In fighting fires in Brisbane at this time and earlier the fire service had access to a *Detailed Fire Survey* of Brisbane City complied by Mahlstedt's consulting fire engineers and surveyors. This survey showed all buildings in the city grid; their construction, number of storeys, stair and lift construction, column layout, fire walls, hydrant locations, whether the building is sprinklered and roof construction. These surveys were updated with the plan of new buildings stuck over the top of demolished buildings, in the 1951 survey 294 Adelaide Street is shown as a proposed building. These surveys aided in the planning of the fire service as to how to approach fire fighting in different buildings depending on their construction. (Lloyd 2007; Mahlstedt 1951)

Fire separation

The extent legislated for fire separation in the Ordinance is that floors are required to be fire-resistant for buildings over four levels. (Chapter 23 1962, 40) Windows in external walls are also limited in size were permitted to take up a maximum of three-fifths of the wall, there were no requirements on the heights of windows to stop smoke and fire rising between floors, but this limitation on the amount of window in each wall has resulted in a floor to floor separation compliant with the *Building Code of Australia* in this case. (Chapter 23 1962, 28)

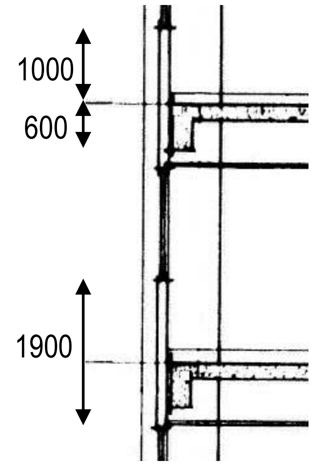

Figure 20: *Section through facade (Fulton Collin Boys Gilmour Trotter & Pins 1972)*

5.4 Shangri-La Hotel - 1991

The Shangri-La Hotel is a fifty-seven storey; two hundred and three metre high office, hotel and retail building. Built in 1991 by Wong & Ouyang (HK) Ltd. 1991 it is located at 88 Queensway, Admiralty, Hong Kong.

This building has been chosen as a case study as it was built after the introduction of the 1989 *Code of practice on provision of means of access for firefighting and rescue purposes* and *Code of practice for fire resisting construction.* The tower itself is also part of a much larger project which as added to the complexity of the fire services within the building. The natural ground falls six levels across the site which contains a large shopping podium, absorbing this fall, the Shangri-La Hotel and Hotel Conrad.

Figure 21: *Shangri-La Hotel, photo by author*

Stairs

Following the introduction of the *Code of practice on provision of means of access for firefighting and rescue purposes* in 1989 the travel distances changed from 36.5m in the 1959 *Code of practice on provision or means of escape in case of fire and allied requirements* to 60m. The obvious impact of this is that it was possible to build bigger buildings with the same number of staircases. (1989b, 9; 1959, 6) The Shangri-La Hotel is divided into three zones; podium, offices and hotel. From levels six to thirty-five there are three rescue stairways and from levels thirty-six to fifty-six there are two rescue stairways. Below level six the number of stairs and their complexity change dramatically as the podium is quite large and the building is on a sloping site.

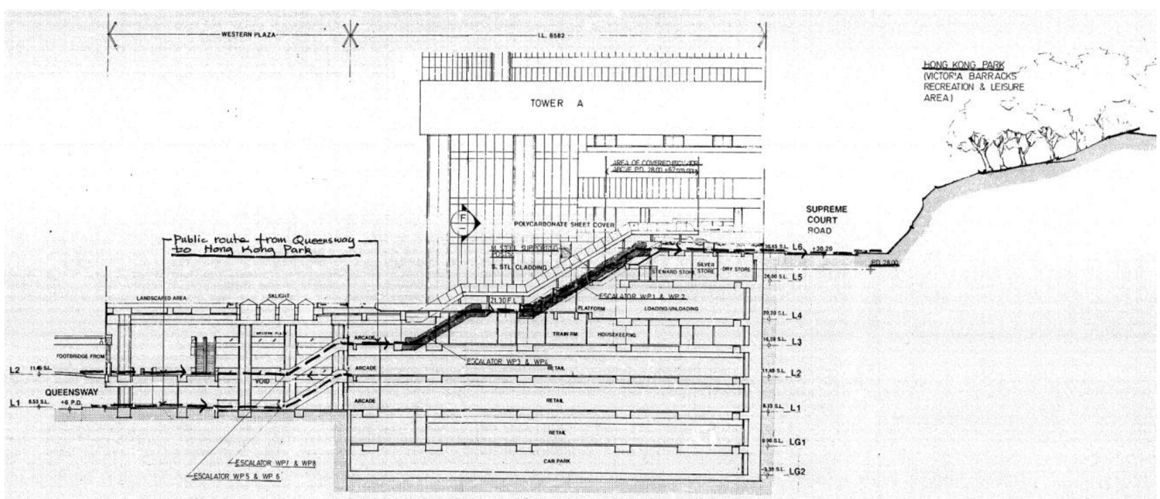

Figure 22: *Section through podium (Wong & Ouyang 1991d)*

There is also a requirement stating that “every firefighting and rescue stairway shall give access to all floors and to any main roof of a building is such roof is accessible by a staircase.” (Building Authority 1989b, 9) Due to the complexity and size of this building not all stairs service every level. Stairs twenty-three and twenty-five service levels six to roof, stair twenty-four services levels six to thirty-five and all other stairs service either the podium or tower B.

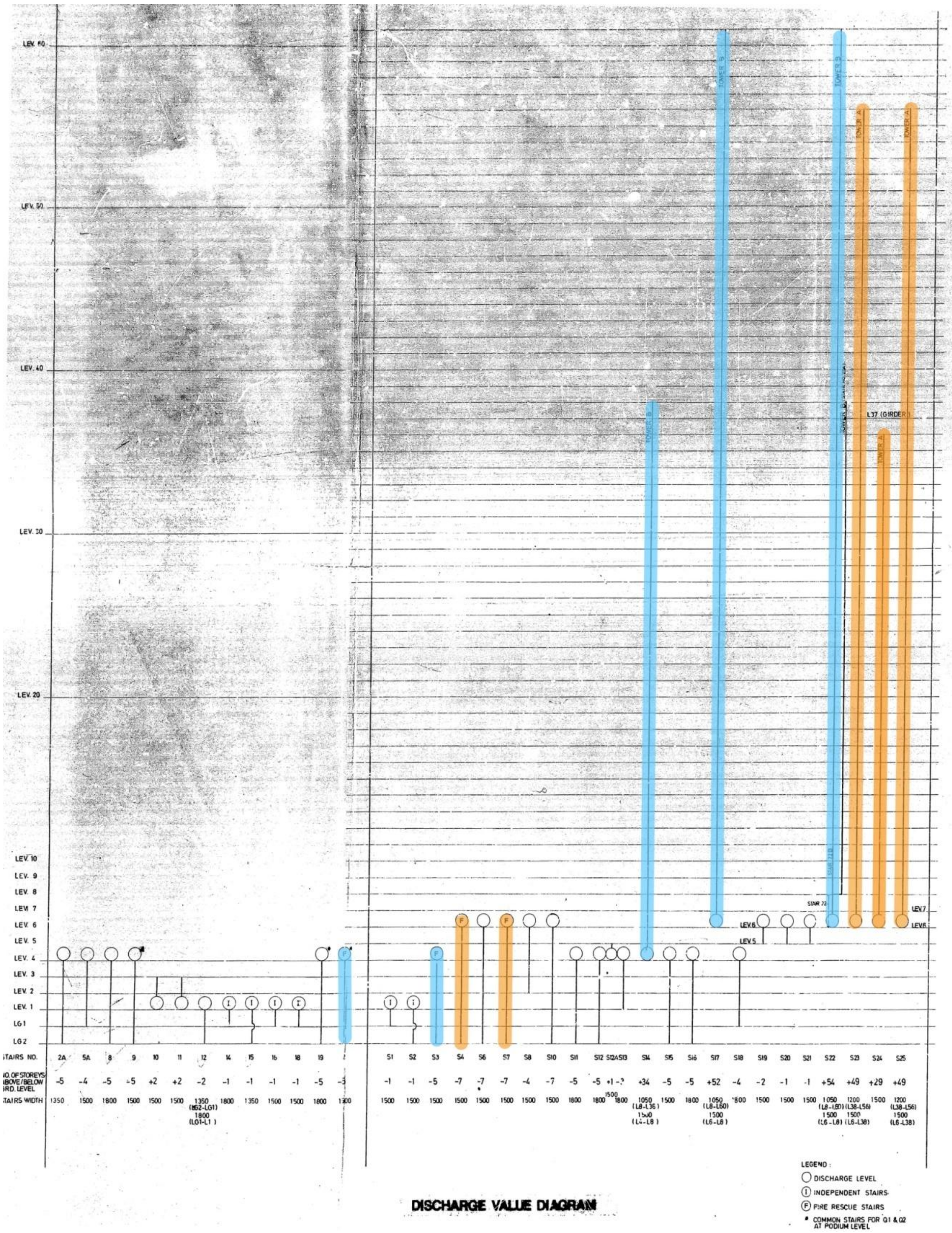

Figure 23: *Stair discharge diagrammatic, Shangri-La Hotel stairs in orange, Hotel Conrad stairs in blue (Wong & Ouyang 1990a).*

As opposed to Australian codes there is no change in the way escape distances are calculated between office buildings and residential or hotel buildings, meaning that escape distances can be measured from any point in the building rather than the door into the hotel room or residence. This building easily meets this requirement but would not have complied under earlier codes when moving around furniture. The greatest travel distance is 35.5m one meter below the older legislation but when accounting for furniture it would be very close to the 36.5m boundary meaning that the building would have needed to be smaller or have a third stair to comply. As the escape distances that this building was designed and constructed under are much larger they have not had an impact on the design of the upper levels. (Public Works Department 1959; Building Authority 1989b)

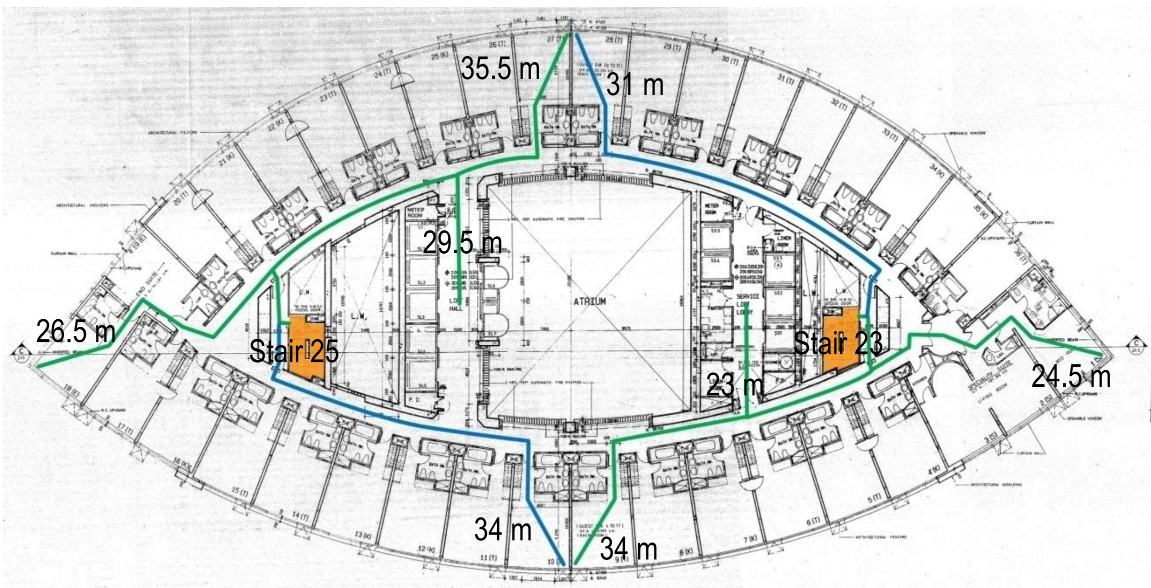

Figure 24: *Hotel upper levels escape distances(Wong & Ouyang 1990g)*

The lower office levels of the building are served by three staircases. The third stair is added adjacent to stair twenty-five creating a scissor stair arrangement. The third stair was not added due to escape distances as it would have easily complied with two stairs. The discharge calculations also show that a third staircase is only needed on level seven not on the office levels above this. The only other reason for this stair is that it discharges on level six into the port cochere and there is a requirement for every firefighting stairway to be situated as close as possible to the perimeter wall that adjoins the closest street used by the fire service, allowing for two stairs to discharge in accordance with this clause. (Building Authority 1989b, 9)

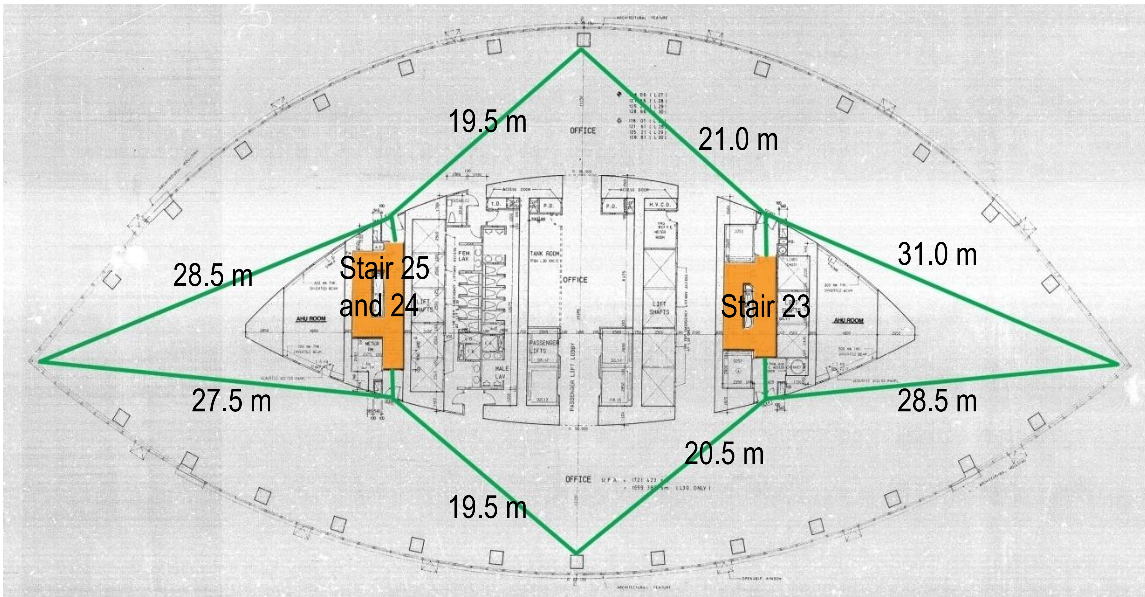

Figure 25: *Lower office levels, escape distances (Wong & Ouyang 1990e)*

In transferring the stairs to the perimeter wall at level nine allow for greater floor area on the levels below for a pool and other hotel related facilities which are located on levels seven and eight. Level nine is a plant floor so there is minimal loss of rentable area. The population on level seven demands a third fire escape because of the potential for a greater number of people to be on this level using the hotel facilities.

Figure 26: *Level 9, Stair Transfer (Wong & Ouyang 1990d)*

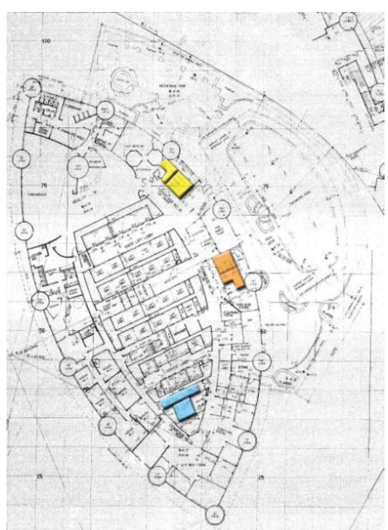

Figure 27: *Level 8 (Wong & Ouyang 1991c)*

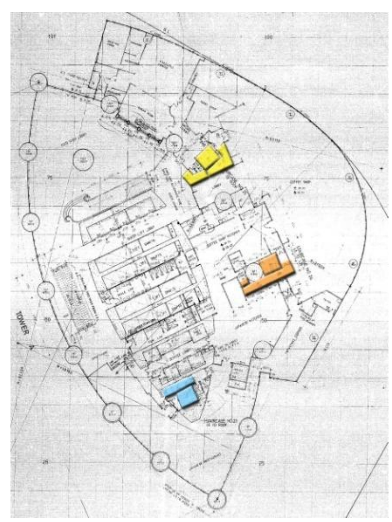

Figure 28: *Level 7, Stair Transfer (Wong & Ouyang 1990c)*

The final requirement of the firefighting and rescue stairways is that they are not to continue and serve basement levels. (Building Authority 1989b, 9) This building is situated on a sloping site and therefore level 6 has been treated at ground level with reference to the Shangri-La Hotel. At this point the stairs servicing the tower stop and new stairs start to continue down to lower ground two. Similarly Hotel Conrad which shares this site is lower on the site and counts level four as ground so its stairs discontinue at a lower level.

Figure 29: *Ground (level 6), orange stairs are acending and blue stairs are decending (Wong & Ouyang 1991b)*

Emergency Lifts

There are two emergency lifts in this building; lift SS3 which services levels three to ten and levels thirty-eight to fifty-six and lift O2S2 which services levels lower ground one to level thirty-seven. These lifts stop on every floor within the zones serviced and when not in use are used as goods lifts.

These two lifts are in separate shafts. They could have shared a lift well as up to three emergency lifts are permitted in a single lift shaft but the planning of the core did not take advantage of this clause. As required these lifts discharge into a lobby with a minimum one hour fire rating. (Building Authority 1989b, 8)

The design implications of using two emergency lifts to service the two zones of the building are that the plan of the core is able to be different in each of the zones. For example as lift O2S2 is in the centre of the plan and serves the office floors, its lift over-run is in the mechanical floor thirty-eight allowing for an atrium to take its place from level thirty-nine to the roof. Similarly one of the fire escape stairs occupies the protected lobby of lift SS3 in the office zone of the building increasing the efficiency of the floor plate.

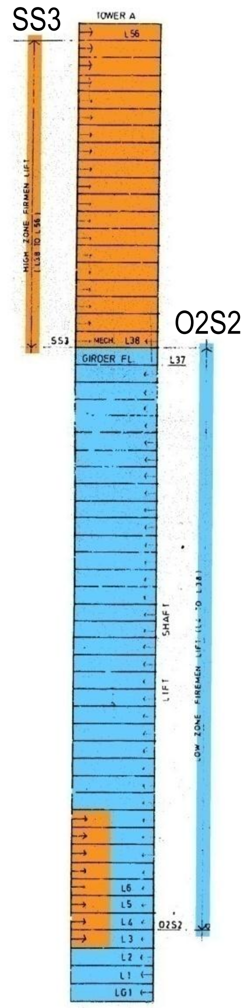

Figure 30: *Floors serviced by each emergency lift (Wong & Ouyang 1990b)*

Refuge

At the time this building was designed and constructed there was no requirement for refuge areas of any description and as a result none were provided. However the emergency lift lobbies are quite spacious, connect directly to a fire stair and could take up this role if required.

Emergency Vehicle Access

Emergency vehicle access is on level four. This is where the sprinkler control valve room is and the fire services control room.

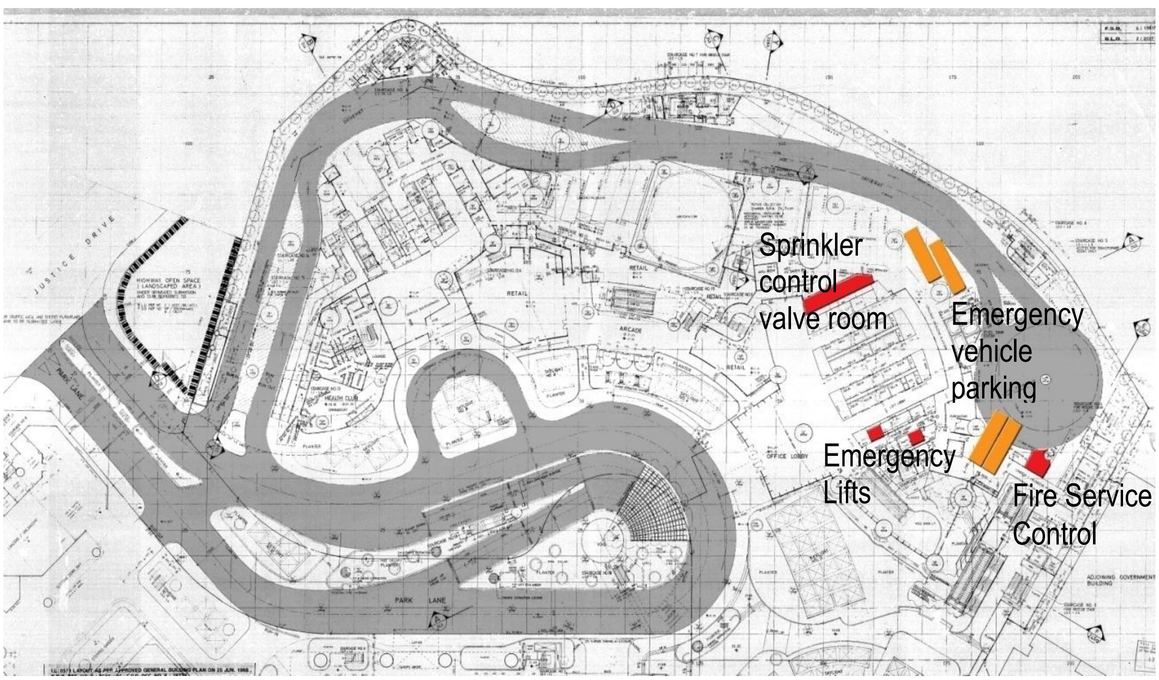

Figure 31: *Level 4 emergency vehicle access (Wong & Ouyang 1991a)*

The design implications of being permitted to have emergency vehicle access on a level below ground is that it gives the architects greater freedom in the design and height of the port cochere, and landscaping at the entry to the building. The location of fire services are also able to be located elsewhere allowing a larger foyer to be created.

Fire separation

The only floor to floor separation legislation which is relevant to this building is the requirement for non-combustible material to fill the void Between the edge of the floor slab and the curtain wall. “To prevent the passage of smoke or flame any void formed between the external wall and the curtain wall should be solidly infilled at each floor level by non-combustible material...” (Building Authority 1989a, 10) In this case the void extends 600 above the slab and 600 below it.

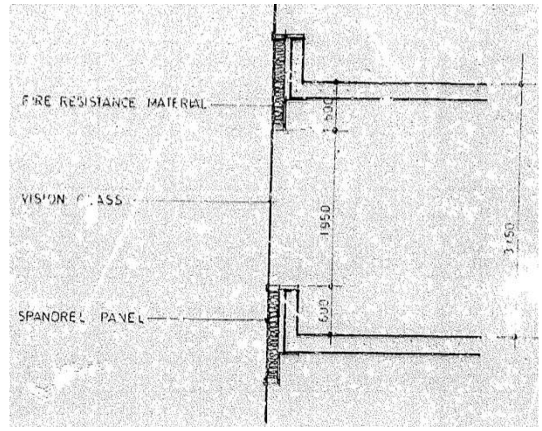

Figure 32: *section through curtain wall (Wong & Ouyang 1990f)*

Another component of the Shangri-la Hotel is that it has a sixteen storey high atrium starting at the thirty-eighth floor.

To stop the spread of fire from floor to floor in this atrium a series of fire shutters have been shown in plan. When activated these shutters compartmentalise the atrium from the rest of the building. (Wong & Ouyang 1990f)

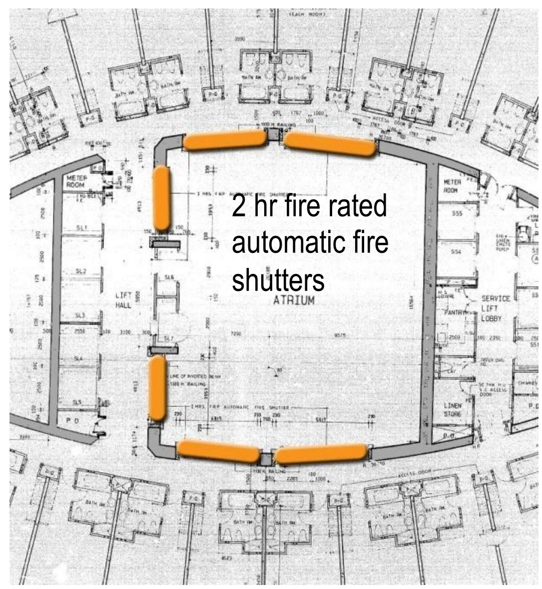

Figure 33: *Atrium (Wong & Ouyang 1990f)*

The design implications of these prescriptive fire separation requirements is that it leaves little opportunity for the introduction of double skin facades and other non-standard passive climate control measures.

5.5 Waterfront Place - 1989

Waterfront Place located at 1 Eagle Street, Brisbane constructed was constructed in 1989. Designed by Cameron Chisholm and Nicol it boasts the largest floor plates in the Brisbane central business district. (Waterfront Place 2007)

This building has been chosen as a case study as it was designed and built under the Queensland Building Act which was introduced in 1975. It is a 162 m high, forty storey office building.

Figure 34: *Waterfront Place, photo by author*

Stairs

This building provides the minimum of two required staircases as outlined in clause 24.32 (3) of the Building Act, it is also fully sprinkled as it is over 42m high. (*The Building Act* 1975, 202) the location of these stairs was decided upon to maximise the rentable floor area of the building. The 1975 Queensland Building Act requires that "where two or more exits are required, no point on a floor shall be more that 18m from – (a) one of those exits; or (b) a point from which travel in different directions to two of those exits is available, in which case the maximum distance to one of those exits shall not exceed 40m." It also states that these exits are not permitted to be closer than 9m or further than 60m apart. (*The Building Act* 1975, 189)

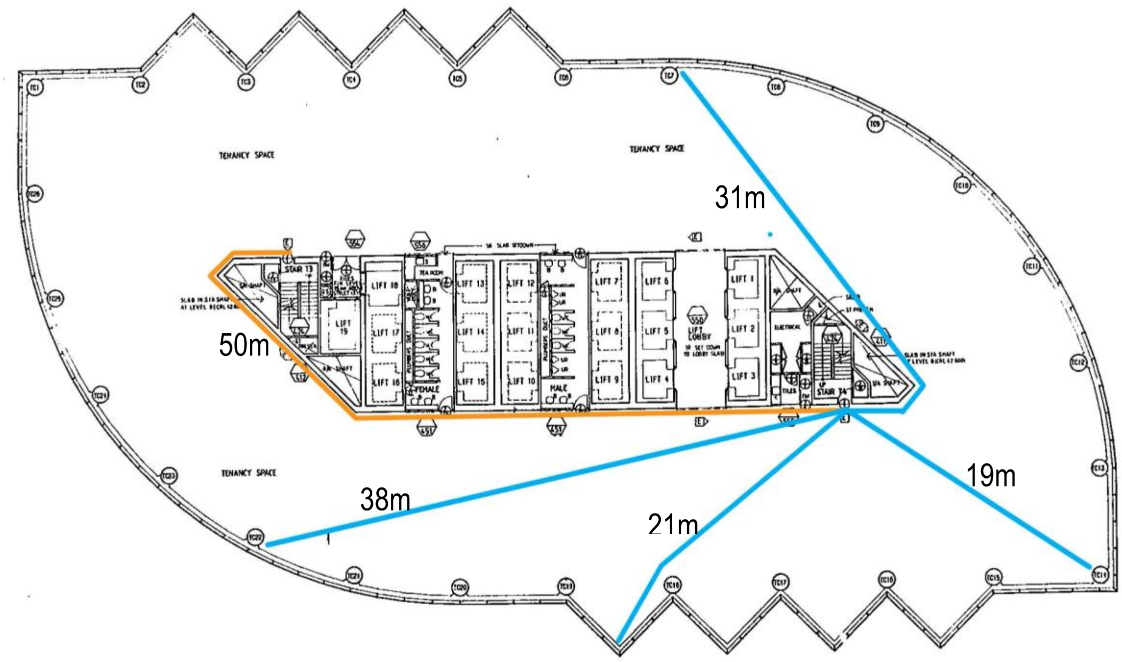

Figure 35: *Travel distances (Cameron Chisholm & Nicol 1987b)*

The design of Waterfront Place places the two stairways at the extremes of the core. The distance between the two stairs is ten metres below the maximum distance they are permitted to be apart. These distances are quite generous but once furniture and partitions are in place, travel distances would be at their limits. Clause 24.44 (2) outlines that once partitions and the like have been installed by tenants these measurement would need to be taken again to ensure that the path of travel is less than 40m to one exit when measuring the path of travel around partitions and furniture. (*The Building Act* 1975, 190)

These stairs are pressurised as required for the exclusion of smoke from fire-isolated stairways for buildings over six storeys. It is permitted that a pressurisation system may serve more than one stairway but the plan of the building does not lend itself to this possibility and as such each stair has its own pressurisation. (*The Building Act* 1975, 250)

Emergency Lifts

As there is a requirement for lifts to be in a fire resisting shaft the design of the building has incorporated these walls into the main structure of the building. Within Waterfront Place there are three lifts in each lift shaft which is constructed of structural concrete walls. There are no stairways and lifts sharing the one shaft complying with clause 23.5 (2) (*The Building Act* 1975, 173)

There are two emergency lifts in Waterfront Place as is required for buildings over 21m with more than two lifts. The primary emergency lift, lift nineteen is the primary service lift and is the required lift large enough for a stretcher with a patient lying horizontally on it. The secondary emergency lift is lift eighteen which serves the upper levels as a normal passenger lift in peek times but at other times of the day is a service lift and an emergency lift when necessary. (*The Building Act* 1975, 253; Peel 2007)

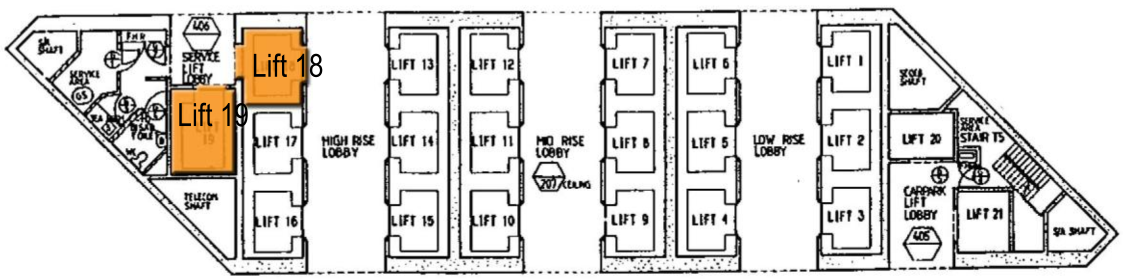

Figure 36: *Location of emergency lifts in core (Cameron Chisholm & Nicol 1987a)*

Refuge

There is no requirement for any type of refuge area and as a result there are no refuge areas provided.

Emergency Vehicle Access

There are two areas for emergency vehicular access; the main entry on the ground floor which leads directly to the fire control room facilities located at the reception desk and the basement car park which is where the pump room is located. In a fire the lifts will return to the ground floor and it is intended that the ground floor will be the first place the fire fighters will go. (Peel 2007)

Fire separation

In the Queensland Building Act there is a requirement for floor to floor separation either in the form of vertical separation or horizontal shelfs. In the instance of a vertical construction the spandrel must be a minimum of 900mm in height with not less than 600mm of that extending above the upper surface of the intervening floor. (*The Building Act* 1975, 166-167)

In the construction of each slab there is formed at the extents of the slab an edge beam and upturn forming a structural separation of 900mm exactly. Although this complies with the first part of the requirements for separation it does not comply with the conditions for a minimum upturn as the upturn is only 270mm high rather than the required 600mm. In interviewing the architects it was stated that a fire engineer was engaged who produced a report outlining that in the event of a fire the fire would move out of the building rather than up the building making it very unlikely that fire could spread from floor to floor. (Cameron Chisholm & Nicol 1987c; Peel 2007)

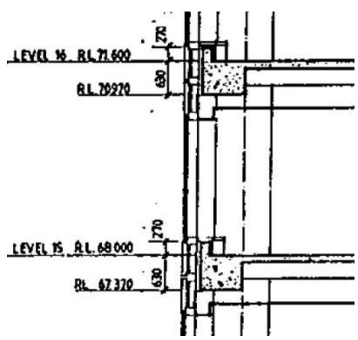

Figure 37: *section through facade (Cameron Chisholm & Nicol 1987c)*


Figure 38: *Facade, photo by author*

5.6 Harbourfront Landmark - 2001

Harbourfront Landmark was constructed 2001 and designed by Dennis Lau & NG Chun Man Architects & Engineers (H.K.) Limited. It is 213m high, seventy storey residential building in Hong Kong.

The podium consists of offices with a resident's pool and spa area as its roof. Interestingly the residential tower has been considered as three towers adjacent to each other replicating fire egress stairs, lifts and services three times.

This building has been chosen as a case study as it was designed and built after Hong Kong codes were revised in 1995-96 to keep up with a building boom at this time. (Howes 2007)

Figure 39: *Harbourfront Landmark, photo by author*

Stairs

With the introduction of the *Code of practice for the provision of means of access for firefighting and rescue purposes* in 1995 the calculation of travel distances changed from being measured to the staircase being measured to the staircases as well as the to the emergency lift. This shift highlights the change in importance the Emergency lift has received in Hong Kong. This adds to the complexity of building as the minimum number of staircases are based on population, distance to the stairwell, height of the building and access routes and between the rescue and firefighting stairwells. (Building Authority 1995)

As with earlier legislation the requirement for buildings over six stories to have two fire stairs has carried over, as has the need to calculate population for building use to determine the number of exit routes that need to be provided. (Building Authority 1996, 13) Based on these calculations the Harbourfront Landmark is required to have two exit routes, as there are no floors with a potential population greater than three hundred and seventy-two people. (DLN Architects & Engineers 2001a)

A new requirement introduced in the 1996 *Code of Practice for the provision of means of escape in case of fire* explains why there are six stairwells serving the domestic floors when only two are required. "Where two or more exit staircases are required, people using one staircase should be able to gain access to at least one of the other staircases at any time without having to pass through other person's private premises. Such access should be provided either at each floor or, where refuge floors are provided, at the refuge floor(s) and the roof. The requirements in this paragraph do not apply to a domestic building or a composite building not exceeding 15 storeys in height above the lowest ground storey." (Building Authority 1996, 13) The design of Harbourfront Landmark is based on the idea that the building is three towers stuck together which is why there are three separate cores. This concept has allowed for six spacious apartments of three or four bedrooms to be placed on each level.

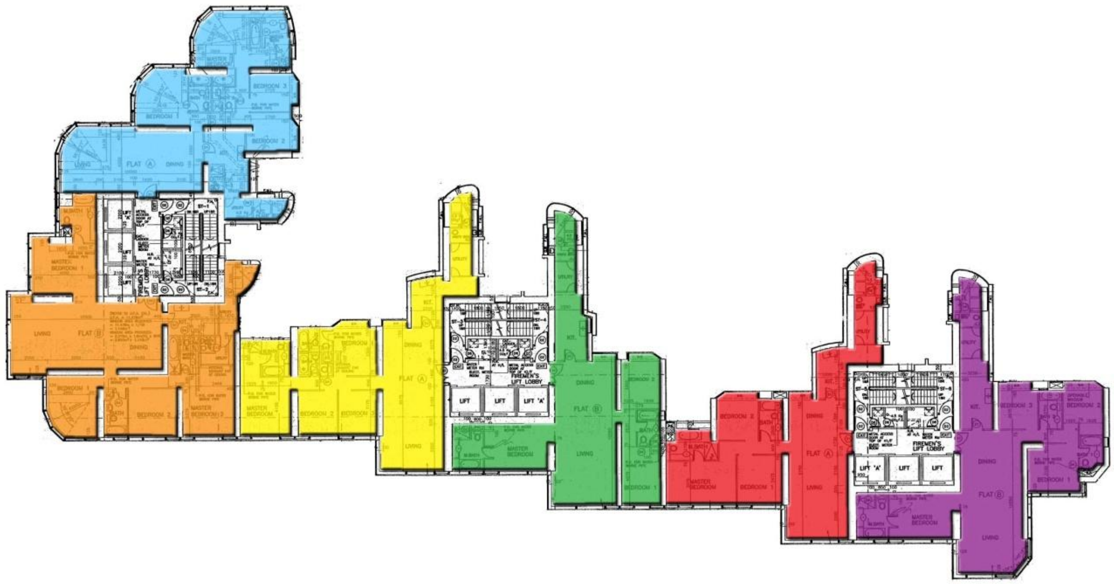

Figure 40: *Apartment layout (DLN Architects & Engineers 2001d)*

The travel distances have reverted back to a much smaller distance following the introduction of the 1996 *Code of Practice for the provision of means of escape in case of fire* which outlines a maximum travel distance of 30m, half of the previous code and 4m less than the 1959 requirements. (Public Works Department 1959, 30; Building Authority 1989b; 1996)

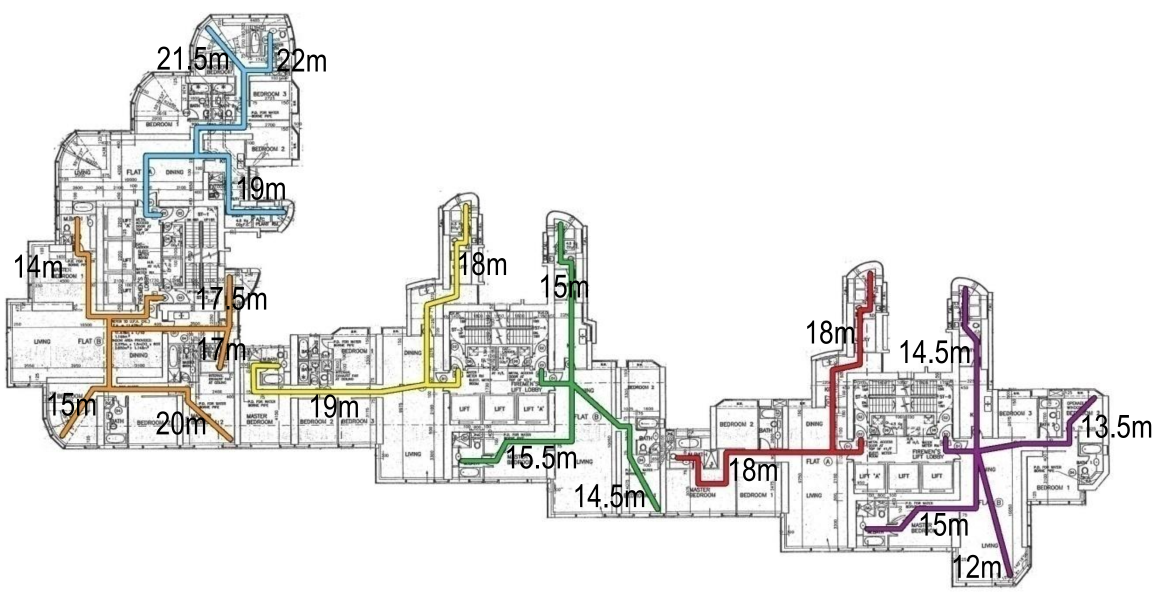

Figure 41: *Travel distances (DLN Architects & Engineers 2001d)*

The above travel distances are well below the maximum 30m allowed by the 1996 code of practice. However the planning, natural ventilation and size of these apartments would not have been possible with fewer staircases. The staircases in this building are naturally vented and as a result are not pressurised.

Interestingly in the office podium of this building an extra three stairwells, there is no distance or population requirement for these extra fire fighting and rescue stairwells which suggests that they have been included for social reasons. In the paper *Aesthetic and Social Aspects of Tallness in Hong Kong,* Haffner suggests that is the security, prestige, economy and well-being associated with tall building that has made them acceptable in the Chinese culture. (Haffner 1991, 25-26) This prestige combined with a class based social structure has made the separation of circulation routes and resultant loss in rentable floor area a necessity.

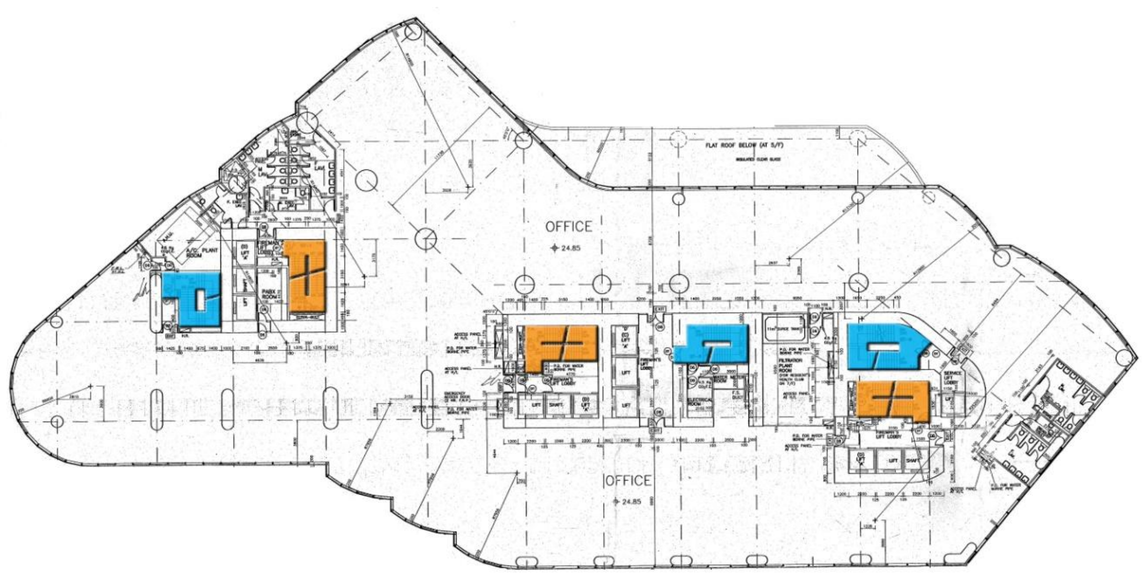

Figure 42: *Podium stairwells; blue stairs only service the podium and orange stairs service the whole building. (DLN Architects & Engineers 2001c)*

Emergency Lifts

As mentioned earlier travel distances to emergency lifts were introduced in the 1995 Code of Practice for the provision of means of access for firefighting and rescue purposes, which states, "no part of the floor served by a fireman's lift should be more than 60m from the door of the lobby measured along actual passage.” (Building Authority 1995, 8) As a result this building contains four emergency lifts, three servicing every floor of the building and one serving the office podium levels. These lifts function and look the same as the standard lifts but are in their own shaft. Because of this design decision to locate all of the lifts together, all of the lifts are accessed through fire isolated emergency lift lobbies.

Another requirement of the emergency lift lobbies is that they are to have “access, without any obstruction and lockable door, to an exit route.” (Building Authority 1995, 9) This requirement directly affects the planning of the core of buildings as it ensures that stairs are located adjacent to the lifts.

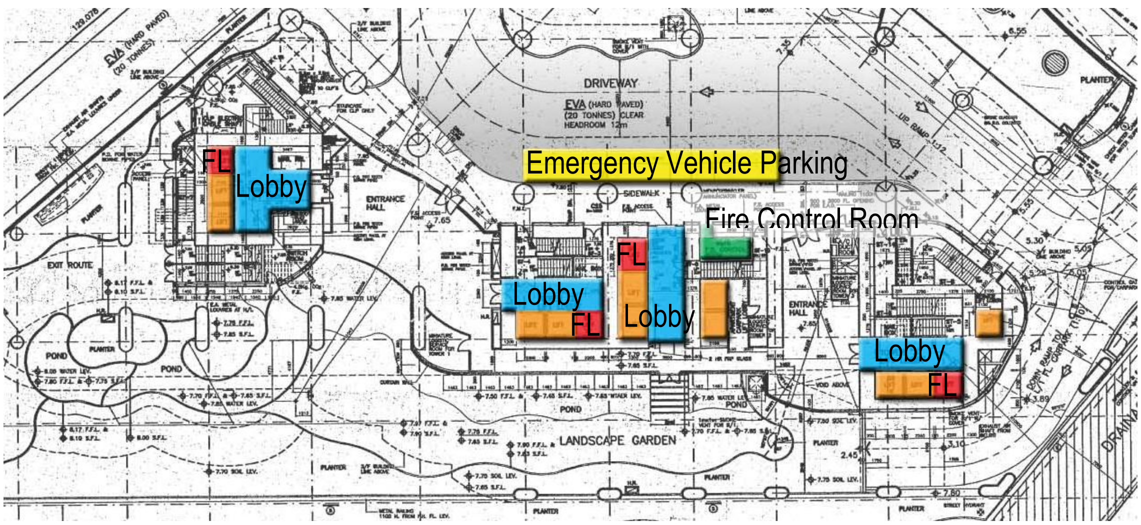

Figure 43: *Emergency Lifts and associated lobbies at ground level (DLN Architects & Engineers 2001b)*

Similarly a constraint on the location of emergency lifts built under the 1995 Code of practice is that they are required to be located such that at the ground access point at the perimeter of the building, the door of the emergency lift is not more than 18m away. (Building Authority 1995, 6) In the case of Harbourfront landmark the emergency lift doors are between two and nine metres from the access perimeter doors, well within the requirements of the legislation.

Refuge

The design premise of Harbourfront Landmark is that the apartments are considered the as three towers adjacent to each other in the design of the building. Each of these towers has a different height and this has a major impact on the location of legislated refuge floors. Refuge floors are required to be provided in all buildings in Hong Kong exceeding twenty-five storeys in height above the lowest ground storey. These refuge floors are to be at intervals of twenty to twenty-five storeys. (Building Authority 1996, 29)

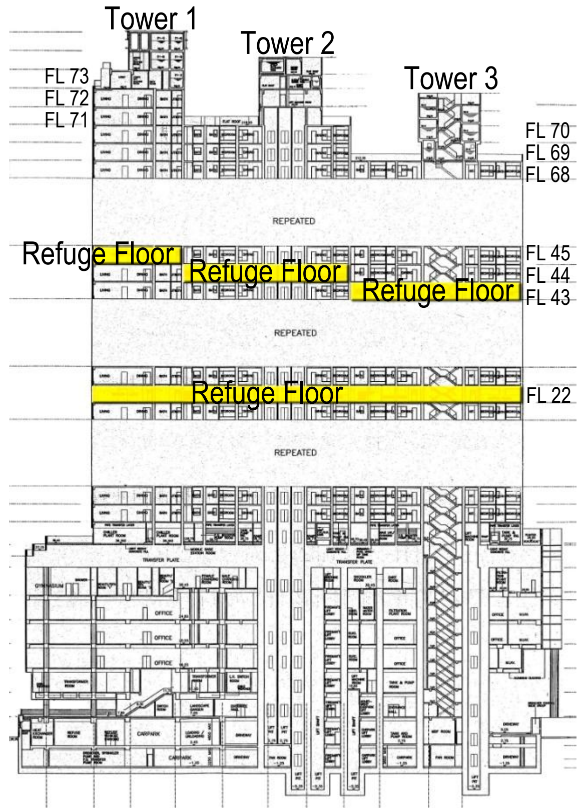

Figure 44: *Section showing refuge floors (DLN Architects & Engineers 2001f)*

Tower one is seventy-five storeys high with the highest habitable floor being level seventy-three. As the penthouse apartments of this tower are split over two floors one of the main fire escape stairs stops at level seventy-two and is replaced by an internal stair in each of the apartments.

When counting the number of storeys to a refuge floor from level seventy two to the first refuge floor on level forty-five there is a twenty-seven storey descent, two storeys over the maximum. The second refuge floor is on level twenty-two and complies with the specified spacing.

Tower two is seventy-four storeys high and has refuge floors on levels forty-four and twenty two. The highest habitable floor is level seventy, twenty six levels above the refuge floor and one level higher than is outlined in the Code of practice.

Tower one is seventy-two floors high with its highest habitable floor on level sixty-eight and refuge floors on levels forty-three and twenty-two. This is the only tower which complies with the refuge maximum spacing of twenty-five storeys between refuge levels, not counting mechanical floors.

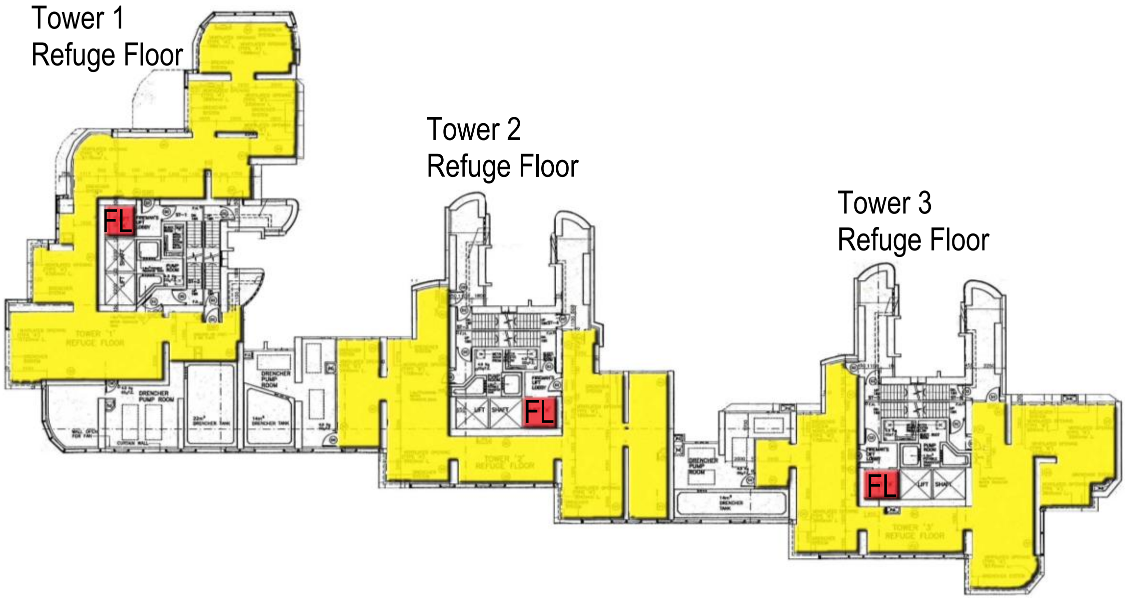

Figure 45: *Level 22, refuge floor (DLN Architects & Engineers 2001e)*

The requirements for refuge floors under the 1996 Code of Practice for the provision of means of escape in case of fire are;

- The only services accessible on the floor are fire services such as water tanks.
- The area for refuge must be at least half of the total gross floor area of the floor.
- The refuge floor must be fire isolated from the rest of the building
- The refuge floor should be open on at least two sides to allow for natural cross ventilation of the floor.
- All staircases that pass through the floor are to discontinue at the floor so that occupants must pass through the refuge area before they continue their decent.
- Emergency lifts must service the refuge floor and they are the only lifts permitted to do so. (Building Authority 1996, 29-30)

Harbourfront landmark has complied with all of these requirements with the area for refuge being one to three square metres over the required fifty percent refuge area in each tower.

Emergency Vehicle Access

Emergency vehicles are able to access Harbourfront Landmark from three sides of the building if needed but it is intended that the primary access point will be from Wan Hoi Street. Parking for emergency vehicles shown in yellow below is under the port cochere which has a clearance of twelve metres for this very purpose. The fire control room of the building shown in green is on the perimeter making it as close as physically possible to the emergency services.

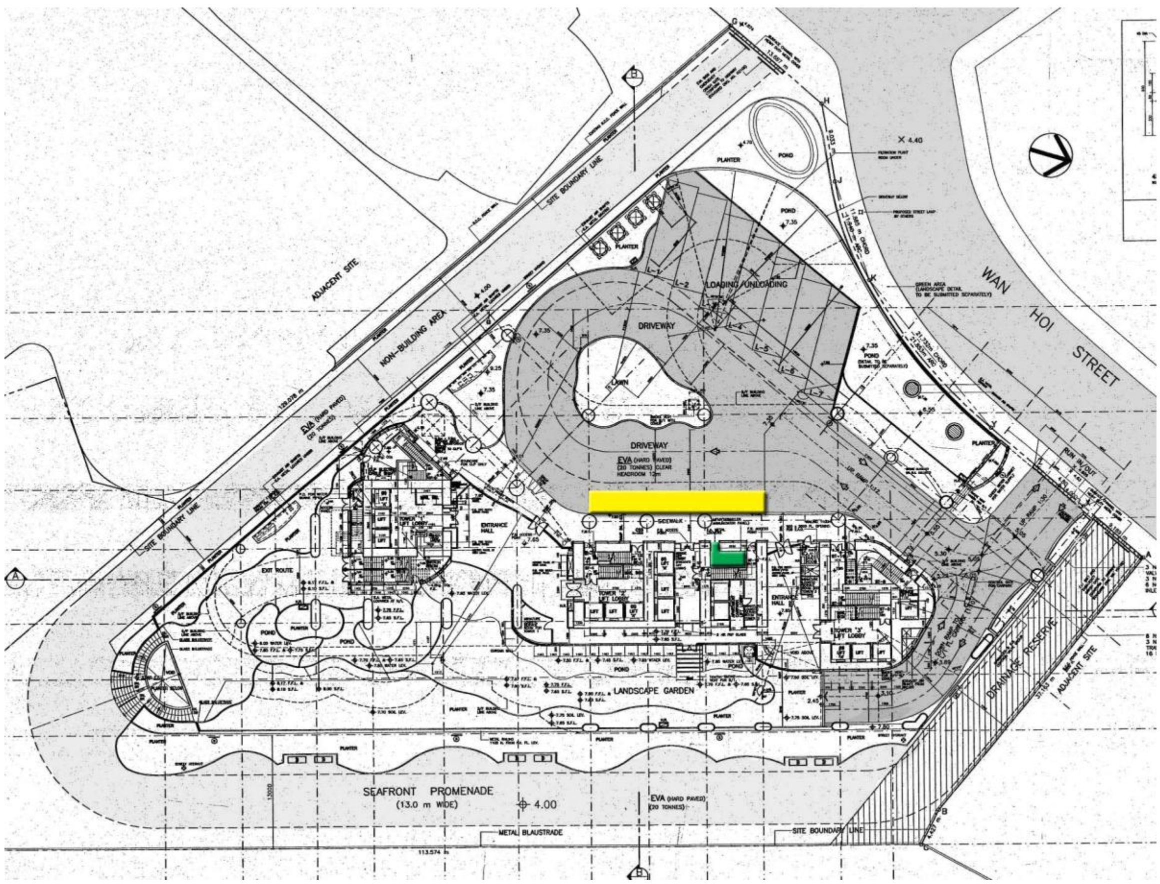

Figure 46: *Emergency vehicle access (DLN Architects & Engineers 2001b)*

Fire separation

The most interesting aspect of fire separation in this building is how the design of the facade has filled the cavity between floors created by the curtain wall to stop the spread of smoke and fire as is required in Hong Kong. Two hour fire rated insulation is placed behind the glass and fire safing is used to close the cavity. This creates a coloured banding on the facade.

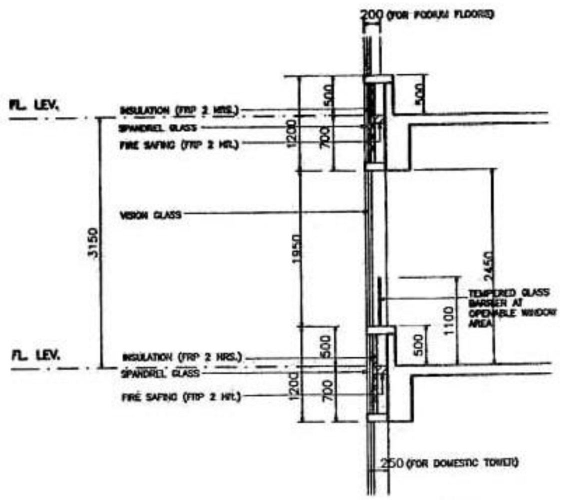

Figure 47: *Section through curtain wall (DLN Architects & Engineers 2001d)*

Figure 48: *Facade of Harbourfront Landmark, photo by author*

5.7 Brisbane Square

Brisbane Square is a thirty-eight storey office building in the heart of Brisbane city. With an overall height of 151m it was designed by Denton Corker Marshall for the Brisbane City Council and Suncorp Metway.

This building was chosen as a case study because it is one of the newest buildings in Brisbane.

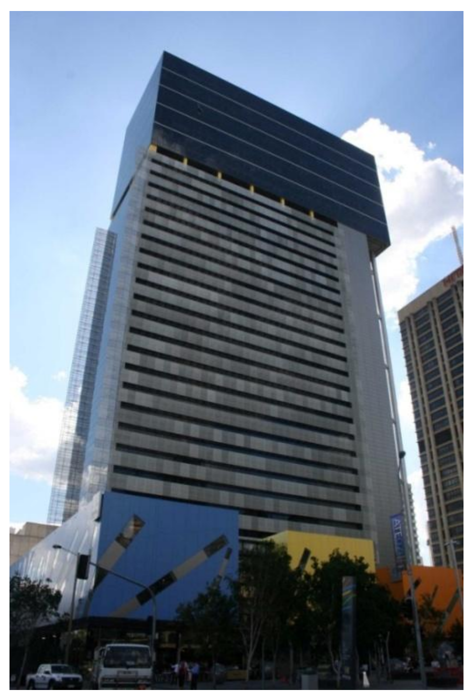

Figure 49: *Brisbane Square, photo by author*

Stairs

The minimum of two fire escape stairwells has been provided in Brisbane Square. Interestingly only one of these stairs forms part of the service core. The second stair in the middle of the plan is necessary due to the size of the floor plate. In accordance with the deemed-to-satisfy provisions of the Building Code of Australia a maximum travel distance of twenty metres to a choice of exits and forty metres to one of those exits is permitted. (Australian Building Codes Board 2006a, 178) If both of these exits were to be part of the core of the building two hundred and eighty square metres would have to be removed from the plan.

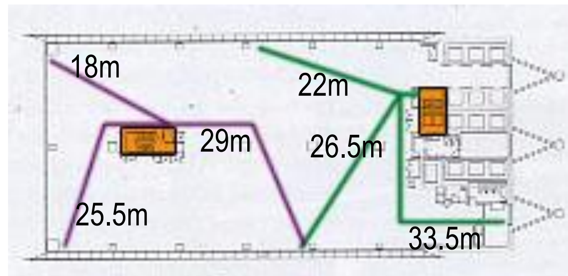

Figure 50: *Travel distances (Beck and Cooper 2007)*

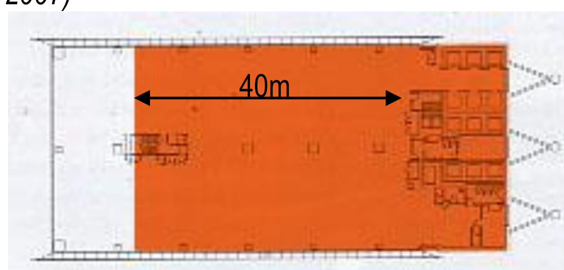

Figure 51: *Extent of plan which potentially could be serviced by stairs in the lift core. (Beck and Cooper 2007)*

In response to industry demands for an obstruction free floor plate side cores have become a desirable design outcome. But as can be seen in the design of Brisbane square the extent of this obstruction free floor plate is limited by the relevant maximum travel distances.

Lifts

“The planning of high-rise office towers is strongly influenced by the location of lift cores. Conventionally, the lift core was located at the centre of the floor plate, but more efficient office planning has shifted cores to the side or across the narrow ends of buildings. Brisbane City Council favoured an end-core layout to maximise office planning flexibility and views. Suncorp favoured a side core layout that better suited its office systems. With some ingenuity, Denton Corker Marshall combines the two lift core types. (The lifts servicing the council offices are located on the east and west sides of the building and extend only as far as the top level of the Council tenancy. Suncorp's lifts are in the centre of the core, with toilets and plant to the west to form a side core.)" (Beck and Cooper 2007, 88)

In buildings over twenty-five metres in height at least one emergency lift is required to be in every lift shaft in the building. In the case of Brisbane Square there are five lift shafts, four passenger lift shafts containing three lifts each and one goods lift in its own shaft.

Refuge

There are no requirements for refuge floors in the Building Code of Australia and as a result no refuge areas have been provided.

Emergency vehicle access

Access for emergency vehicles to Brisbane Square is via George Street. The fire control room is accessed from this street and the foyer. A fire control room is required for all buildings over fifty metres in height, it must have accessible via two paths of travel, one from the front entrance of the buildings and the other directly from the street which evident in the design of Brisbane Square. (Australian Building Codes Board 2006a, 241-242)

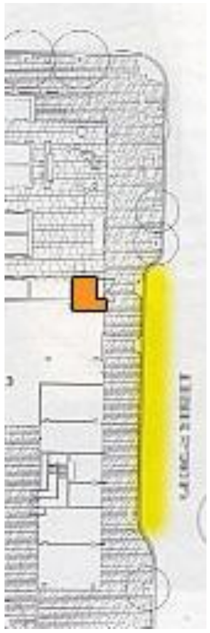

Figure 52: *Ground floor (Beck and Cooper 2007)*

Figure 53: *Fire control room, photo by author*

Figure 54: *Emergency vehicle bay, photo by author*

Fire Separation

“In accordance with the brief for an economical high-rise, Denton Corker Marshall designed the building as a glass box with state-of-the-art curtain wall glazing technology that achieves a five-green star rating.” (Beck and Cooper 2007, 88) Contrary to the requirements outlined in the Queensland 1975 Building Act and Hong Kong fire codes, the 2006 Building Code of Australia deemed-to-satisfy provisions allow curtain walls of non-combustible construction, fully protected by automatic external wall-wetting sprinklers to not have a Fire Resistance Level. (Australian Building Codes Board 2006a, 125)

Conclusion

In conclusion the legislation of fire safety has had a significant impact on the design of tall buildings. However it is evident that except in extemporary case of Alexandra House fire safety measures are only integrated into the building to the extent that is required by legislation. All of the buildings studied have complied with the regulations placed upon them but have not gone beyond these requirements to integrate best practice into the building.

It can be seen in each of the buildings studied above except for 294 Adelaide Street that maximum travel distances have played a major role in determining the overall size of floor plates. Changes in travel distances between countries and over the years have produced buildings of different sizes accordingly. Legislation on the requirement of protected lobbies in Hong Kong has had a direct impact on the size of floor plates and the planning of cores to get this lobby to serve more than just the stairwells it is required to, similarly in Australia where protected lobbies are not required the location of stairwells have adjusted accordingly.

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