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THE ECONOMICS OF SUPER-TALL TOWERS

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SUMMARY

This paper addresses global economic factors influencing the decisions leading to the development of super-tall towers, including population growth and urbanization, economic cycles and the 'Skyscraper Index', regulation and 'regulatory tax', and resource availability. The project economics of individual developments are then explored with respect to construction costs. The development, design and construction challenges that impact on cost are also discussed. Furthermore, a breakdown of costs is given in the form of an indicative cost model (for a central London landmark tower) from cost data collected by Davis Langdon in the course of their work as construction consultants. Copyright © 2007 John Wiley & Sons, Ltd.

1. INTRODUCTION

In 1930 Clark and Kingston (cited in Klaber, 1930) made the following observations in their publication *The Skyscraper: A Study of its Economic Height*:

> Given the high land values in central business sections of our leading cities, the skyscraper is not only the most efficient, but the only economic utilization of certain strategic plots. An exhaustive investigation . . . has conclusively demonstrated that the factors making for diminishing returns in the intensive development of such plots are more than offset by the factors making for increasing returns . . . Measured by its contribution to public welfare, [the skyscraper] deserves to rank with the telephone and the automobile as one of the great modern inventions.

This statement still holds true in many senses, though the quantification of both cost and benefit becomes more complex in today's global marketplace and increasingly environmentally aware world.

The specialist industry expertise developed for super-tall tower (STT) projects and the increasing division of labour, due to the global nature of STT development, will inevitably require redefinition with regard to the measurement and reporting of the less tangible impacts of buildings. The STT sector is particularly susceptible to any legislative changes regarding energy use, as towers typically require some 30% more energy and materials in their construction and operation than other functionally comparable buildings (CNN, 2007).

Construction costs are well understood (by those with the requisite knowledge and experience), as are directly realized benefits such as floor space and rental income. However, embodied energy, costs in use, infrastructure load, CO_2 emissions and cultural and social capital are more difficult to ascribe meaningful values to in respect of the construction and operation of STTs. Projected occupancy costs, tenant modifications and eventual demolition (Carmody and Trusty, 2005) are factors becoming

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increasingly important in the financial equation, which reflects the triple bottom line of environmental, social and economic value of STTs.

As such, the goalposts are set to move, influenced by global and local urban environment initiatives that will impact what we can build tomorrow, and the value of what we have built to date.

To enable a discussion of STTs and the factors influencing their development, a definition is required. It is not as simple as assigning a certain height due to the differing perception of height with respect to the location and context of the proposed tower. For example, a 10-storey building in a location of predominantly three to four storeys could be considered 'super-tall' but not in terms of a hypothetical definition based on a minimum storey height of, say, 50 storeys. Furthermore, a definition derived purely on a specific height dimension does not convey the complexity and challenges particular to STT.

2. TOWARDS A DEFINITION OF 'SUPER-TALL TOWERS'

A good starting point in developing a definition would be Miller (2000) and their analysis of large engineering projects (LEP) using 40 case studies, from oil rigs to seaports, airports to motorways. Their derived LEP definition and characteristics, as detailed below, perhaps make a tower project a 'super-tall' one:

- *product of negotiated compromise*: customised to meet client requirements;
- *integrated parts of infrastructure networks*;
- *contested externalities*: facing potential community challenge and international pressure groups' opposition;
- *crafted over many years*: front end period to consider development/feasibility issues extends beyond that of an 'average' construction project;
- *exposed to political risk*: political considerations influence initiation; viewed as a vehicle for economic development;
- *complying across multiple regulatory frameworks*: facing highly developed regulatory frameworks; having to deal with multiple uncoordinated agencies;
- *large, irreversible commitments*: with respect to financial commitment.

It should be noted that some very tall buildings do not fit with this criteria of the LEP. For example, government-funded residential towers in the Asia Pacific region may be taller than any commercial tower in London and be subject to the technical considerations that are implicit in their height; yet in design, procurement, and risk profile they are qualitatively less complex.

Certainly Miller (2000) definition of LEPs as 'unique, dedicated, and usually one-off products, with intensive interactions between sponsors and contractors' can form part of the STT definition.

The LEP criteria, combined with our experience of delivering STTs, leads us to a definition encompassing the following key themes behind STT development:

- extended duration;
- international effort;
- STT as a product.

The links between these three themes define the demand, supply and delivery drivers influencing STT development and their economics. (see figure 1)

Thus, it can be said that STT development is more susceptible to global macro-economic trends than (at least most) other sectors of the construction industry. In part, this can be attributed to the cost concentration in the three principal elements of structure, façade and services, and their price

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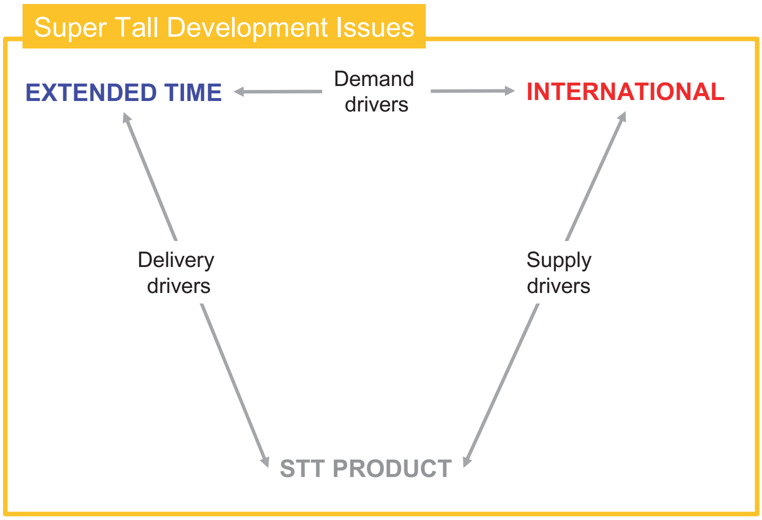

Figure 1. Illustration of the drivers of STT development

fluctuation due to currency exchange rates and global demand cycles. Furthermore, these elements are increasingly being procured from the global market place and, as such, consideration of an STT requires an assessment of some of the global factors that contribute to the risk profile of STT development.

3. EXTENDED TIME—INTERNATIONAL: DEMAND DRIVERS

The interaction of these two themes and thus the drivers creating the current demand for STT can be summarized as follows:

- urbanizing populations and unprecedented levels of global city growth are generating the demand for STTs worldwide;
- the extended duration of STT development means traversing multiple political, economic, social, technological, legal and environmental (PESTLE) cycles. This heightens the number and complexity of risks involved.

3.1 Urbanizing populations and city maturity

Population growth and building booms

Fifty per cent of the world's population now live in cities (United Nations Fund for Population Activities, UNFPA, 2007), and this figure is set to rise dramatically over the next 50 years. Rapid population growth in the Gulf states of the Middle East has been occasioned by an influx of skilled foreign workers requiring central residential and commercial accommodation, with foreign labour brought in to help build the accommodation required. Similar labour and skills migrations are being driven by construction booms across China, with its population of some 1·3 billion. This 'migration' is particularly influenced by the development of international business areas like Shanghai's Pudong International Trade and Finance Zone and the movement of rural populations to sprawling periurban areas.

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Urbanization and economic prosperity

Increased urbanization, properly planned, will tend to lead to increased affluence, which will support the future development of STTs. The STT and its use—whether it is office, retail, residential, hotel, cultural or mixed use—is a luxury commodity. Super grade A office accommodation, six-star hotel rooms and serviced apartments are spaces for the most successful corporations and individuals. However, burgeoning urban populations will also drive the need for 'affordable STTs', with a predictable increase in demand for suitable land, affecting land prices and the amount of occupiable space needed to be developed thereon to provide a viable return on investment.

Morton and Jaggar (1995) make the link between plot ratios and STTs:

> . . . where there is an intense demand for accommodation, . . . such as near the centre of a prosperous city, the very possibility of building high . . . itself pushes up land prices. This in turn means that tall building becomes cost effective, as the high cost of the land is distributed over a greater lettable floor area of building.

Characteristics of the city: STT attractors

This increased urbanization around the world, particularly in the emerging economies of China and the Middle East, has led to a growth in the number of cities vying for the attention of global corporations to site their regional or global headquarters in their city. As countries and cities compete to attract global businesses, benevolent commercial legislation and planning regulation are seen as incentives to investment in STTs. There are a number of factors, detailed below and drawn from the Global Financial Centres Index, that contribute to the magnetism of profitable cities, leading to higher densities of higher-value businesses being drawn to locate in them:

- *People*: the concentration of 'human capital' found in a city relates to the quality of life and available amenities.
- *The availability of human capital*: may ultimately determine the citing of international headquarters.
- *The 'business environment'*: economic regulation and taxation, proximity to financial markets and ease of doing business within a city all contribute to attracting international businesses to locate in those cities that provide superior business environments.
- *Market access*: facilitated by the availability of capital and volume of trade, combined with the provision of legal and accounting services to the financial sector, with higher concentration of these factors making cities and such locations within cities more attractive to tenants in the financial, insurance, and real estate (FIRE) sectors.
- *Accommodation availability*: focusing on quality, availability and occupancy cost of office space, with the ongoing 'competitive attractiveness' of cities directly depending on its ability, all things considered, to provide suitable space.
- *Transport Infrastructure*: provision of infrastructure that is of sufficient quality, safety and capacity, which provides accessibility/proximity to global transport hubs.

Regeneration and 'boosterism'

The lower investment returns available in economically less vibrant areas will preclude the building of STTs—unless their developers are given specific incentives to build in such 'preferred areas' due to land shortage, planning/heritage issues, unsustainable densities and the like. Examples of such 'enterprise zones' are London's Docklands, and Shanghai's Lujiazui Trade and Enterprise Zone in Pudong, where the initial 'magnet' towers—1 Canada Square and Jin Mao Tower, respectively—were given favourable tax concessions and supported by significant government infrastructure investment.

Indeed Jin Mao—as with many towers in China, the Pacific Rim and Middle East—was largely government funded. Similarly, in boosting the regeneration of Lower Manhattan, the building of Goldman Sachs' new high-rise headquarters is supported by a raft of government incentives. This 'boosterism' is seen as necessary for both regional or satellite cities and for incentivizing investment in development zones in established cities.

Projects like the Bilbao Guggenheim Museum, by Frank O. Gehry, provided cultural capital and economic momentum similar to the building of an STT, creating an icon for the city. This has led to the coining of the term 'Bilbao effect', where the regeneration inspired by one building can propagate the success of an entire city, local clusters of high-value adding businesses within the city, landmark buildings and STTs.

3.2 Economic cycles and optimal height

Barr (2007) notes that the height of new skyscrapers does not simply increase year on year, as the factors determining 'optimal' height relate to global, national and city economies and their respective regulations. An economically optimal height would be the maximum height (and maximum floor space) as dictated by the net return on investment, i.e. the height at which the marginal cost of creating another floor is equal to the sales price realized for that floor.

Barr finds no recent research on economic drivers for construction of (specifically) tall buildings. However, there is much affiliated research on economic cycles, the influence of regulation, money supply, and the hierarchies of sectors and industries, that has been applied to the STT phenomenon.

Cantillon

Lower interest rates stimulate money supply, and the economic effects which follow on from money supply were first described by Cantillon (1735) and later called Cantillon effects. The primary Cantillon effect is that money supply for investment, whether from government or private sources, becomes a magnet for further investment, raising prices where economic activity becomes more concentrated.

The effect of low interest and high money supply is as a driver for investment in more highly capital-intensive projects such as land and (large) buildings. The lowered opportunity cost of investment when debt-servicing costs are reduced leads to larger investments and hence taller buildings. Various parts of the world have experienced this scenario in recent years, but the current widespread credit squeeze could cause this effect to be reversed—to what extent we are yet to witness.

In times or areas of low interest rates, land with the highest concentration of value-adding activities will increase more in value than land that is given to less valuable activities. Thus prestige city centre land, the likely site for STTs, is likely to have the highest increase in capital value. The increased cost of land heightens the economic need for developers to build tall to mitigate the costs of the land. Furthermore, in times of low inflation the FIRE industries which dominate central business districts tend to grow, further increasing the desire for space within these particular areas and thus increasing the land values and sharpening the demand and supply-side drivers for building tall. Thornton (2005) posited these 'Cantillon effects' as the root of what Andrew Lawrence (1999) dubbed the Skyscraper Index.

Skyscraper Index

It was the ready availability of cheap debt finance that Andrew Lawrence (1999) hypothesized to be 'causal' in his analysis of economic cycles and skyscraper construction. His research focused on a correlation between the construction period of each of the world's tallest buildings, and coincidental

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widespread financial collapse. The Chrysler and Empire State buildings were completed in 1930, one year into the Great Depression (1929). Similarly the World Trade Center (1972–3) and the Sears Tower (1974) were completed in the midst of American stagflation. The last example of the Skyscraper Index was the Asian financial crisis in 1997, which occurred as the Petronas Towers in Malaysia were nearing completion (1998). The correlation, though not perfect, holds for most of the buildings that held the title of 'world's tallest' throughout the 20th century, but whether this is causal—and whether it holds for today's globalized economy—is a moot point.

Economic cycles: Malaysia and UK

Analysis of individual economies shows that the construction sector follows similar trends to Gross Domestic Product, though with more extreme cycles, and with a lag of 1–4 years. The boom and bust cycles of GDP and construction growth in Malaysia bear out the Skyscraper Index (Madya *et al.*, 2004). Though 1 Canada Square was not the world's tallest, it remains the tallest in the UK since its completion (1991). It was completed in a period of economic recession that could not have been predicted when construction was commenced during a period of sustained and stable growth (Latham, 1994).

Black leverage

The leverage from debt-financing of highly capital-intensive investments such as STTs offers developers large potential gains. However, within the long programme durations of such projects the economic climate can change. STTs which become available to let in economic downturns can suffer from under-occupancy and rising interest rates on large debts. This is called 'black leverage'. Even in these conditions Charney (2005) notes that STTs achieve higher occupancy rates than other buildings in the same market, which somewhat mitigates the black leverage effect of potential economic downturns.

Lag and programme

The out-of-sequence cycle of the construction industry, with a lag to GDP detailed above, is of particular relevance and risk to the construction of STTs. One factor contributing to the risk is that construction of STTs can rarely be halted midway in response to declining demand-side economies.

3.3 Legal and regulatory considerations

Increased regulation in cities

All other factors accepted, development of STTs is most likely to occur in or in close proximity to areas that already provide dependable infrastructure and adequate amenities. Hilber and Robert-Nicoud (2006) developed the proposition that the more such areas become developed, the more heavily regulated they become. This cost of compliance, labelled as 'regulatory tax' (RT) (Glaeser *et al.*, 2005), serves to slow development and restrict supply.

Sunk costs

In practice, complying with the regulatory environments of cities large enough to support STTs, is a time-consuming process that contributes to extending the duration of STT development and can result in significant sunk costs. RT costs add to the development programme and budget, impacting on commercial viability. In established metropolitan areas such as Manhattan, RT costs can account for 50% of the cost of residential property.

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Changes to legislation

Some changes to legislation are driven by economic factors such as the introduction of a capital gains tax on second homes, or homes owned for less than 5 years in China, which is expected to calm escalating residential prices as a result.

Changes to planning legislation represent a constant struggle to balance the protection of heritage and the aesthetic and other characteristics of a cityscape with economic need. Hence the appearance of Canary Wharf (London), La Défense (Paris), Potsdamerplatz (Berlin) and Lujiazui (Shanghai). For example, the 1991 Supplementary Planning Guidance for London on the Protection of Strategic Views was updated in February 2007 to alter (generally relax) the 'panoramas', 'river prospects', and 'townscape views'.

The effect of such town planning restrictions can be seen in towers such as the Leadenhall Building in the City of London, whose shape was largely determined by the protected view of St Paul's Cathedral from Fleet Street.

Sustainability

In Europe, government policy towards 'sustainability' is significantly changing the legal and regulatory landscape. The European Building Performance Directive (EBPD)—which needs to be adopted by all EU member countries—focuses on reducing carbon emissions arising from the construction process, including the manufacture of building materials and components, and the building as 'end product' with the imminent introduction of an energy label that grades a building's energy efficiency.

There are a number of legislative influences and requirements that need to be addressed, for example in London: Building Research Establishment Environmental Assessment Method (BREEAM); Greater London Authority Renewables Targets; Building Regulations (Part L—Energy Efficiency); Aggregates Tax; etc. While these combine to create a situation that is not completely clear, it does appear that the focus of developers and investors is beginning to shift from what they *have to* do to enhance the 'green' credentials of their tall (and other) buildings to what they *can* do. This is no doubt a consequence of the corporate social responsibility agenda of their boardrooms—and those of their potential tenants.

4. INTERNATIONAL—STT PRODUCT: SUPPLY DRIVERS

Predominantly, this is an issue of resourcing from the global marketplace. Key issues driving and influencing supply include:

- globalization and international procurement opportunities with regard to the three main elements of an STT contributing the majority of construction cost namely: structure, services and façades;
- the specialized commodities, skills and people, contributing to the STT sector, are limited in number and are drawn from an increasingly competitive global market.

4.1 Globalization and resource availability

Global demand

Increasing globalization—and the options it presents for international procurement—has perhaps brought an end to the 'Skyscraper Index'. However, global competition for construction resources—labour, plant and materials—is leading to construction cost inflation and volatility due to the unprecedented global demand. STTs are perhaps more acutely affected in this respect due to the limited pool of people and companies with the requisite skills and experience to help construct them.

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Construction resources and their availability—whether management or trade skills, materials manufacture or supply, or plant, such as tower cranes—are becoming global commodities, with their cost becoming less of a local issue and increasingly a global cost driver. This is a relatively new trend in construction markets, some of which can be attributed to an unprecedented increase in STT development, and other mega-projects globally.

Global supply chains, international procurement
In order to take advantage of the opportunities presented by the global market, however, close risk and programme management needs to be observed, as the complexity of STT project specifications and delivery pressures increase with the rise in the number of locations being procured from. While cost efficiency may be the initial spur to consider international procurement strategies, quality control during (long-distance) manufacture, material and component testing, logistics management, customs and excise duties, holding costs and delivery on time (often to meet fast-track construction programmes) and code compliance all impact on the programme and cost.

Risk and planning
Risk over time is one of the defining features of STT projects, partly due to design and development durations in excess of normal construction projects.

The development duration for an STT from feasibility to delivery can be over 10 years. The complex considerations of financial planning and managing risk over such a period may span more than one boom or bust cycle in the global context and is an area of cost, time, risk and value management requiring specialist expertise and experience.

Linked to the global knowledge implicit in the above, a deep understanding of the local market where the STT is being built is also essential in properly developing relevant risk strategies and managing them.

4.2 Specialized commodities, skills and people

The STT project, due to the nature of manufacturing processes, i.e., the turning of raw materials into finished product, is at considerable supply-side risk. This risk is further heightened by the increasing use of pre-fabrication and off-site construction in STTs, which draws on manufacturers and suppliers that have highly specialist and finite global capacity. Unitized curtain walling systems are an example of this finite global resource necessitating early pre-ordering, to ensure that manufacture and delivery times coincide with construction programmes. As such, securing main contractors and specialists such as curtain walling manufacturers at an early stage—and having assurance of their continued involvement—is emerging as a key criterion in planning, procuring and managing the development risk of STTs.

One mechanism available that can help to mitigate the risk is to negotiate ‘fix only’ contracts for materials or components directly procured by the client or on his behalf. Such arrangements may challenge conventional contractor or subcontractor relationships in some markets and will certainly require performance warranties, repair and maintenance considerations to be revisited.

An experienced team with global reach, combined with local knowledge and global delivery capabilities, is a further mechanism that can limit risk. The risk that inexperienced consultants or contractors will bid for and win contracts through lower pricing based on flawed assumptions is called the ‘winner’s curse’, as complex realities in project execution overtake the capabilities of the winner (Miller, 2000).

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Miller and Lessard also highlight potential responses to risk that detail the importance of experience among the co-specialized partners. Suggested strategies include:

- the creation of project teams that have the necessary skills and information, e.g. best (global) practice and local (specific) procedures;
- allocation of different risks to relevant parties best able to frame and bear them;
- devote longer programme durations to the planning of the execution sequence of the STT product.

5. EXTENDED TIME—STT PRODUCT: DELIVERY DRIVERS

Essentially a logistics and programme management issue, the effects the extended time has on the STT product include the following:

- Managing the large number of stakeholders and their expectations over the extended duration is a key project governance issue for STT development.
- The technical challenges arising in the design and construction of STTs are distinct from those of more common building types. The impact of dealing with these is a contributing factor to build costs and programme duration.

This section ends with the provision of a cost model that attempts to link some of the macro factors described above to local project economics. The commentary and costs are drawn from an article in *Building* magazine, published in May 2007, by Davis Langdon.

While recognizing the regional variables highlighted above and to provide for focused discussion on the construction costs of STTs, the cost model refers to an STT development in central London.

5.1 Stakeholder management

From the outset, the increased level of scrutiny in terms of a tower's impact architecturally, environmentally and economically and the greater number of stakeholders involved in an STT development present a manifold of challenges, in particular, making a viable business case relevant to the objectives and value criteria held by each of them:

- to the city—the 'signpost value' of a landmark building—e.g. Commerzbank building in Frankfurt which, on completion, became the symbol used in the *Financial Times* to identify that city;
- to the community at large—and the 'access value' provided—e.g. the much improved transport infrastructure required to commercially service Canary Wharf;
- to the planning authorities—and the planning application process—requires significant effort, time and money to be invested to help the project through the planning and consultation processes;
- to prospective owners or occupiers of a landmark or iconic building—e.g. Swiss Reinsurance Building (the 'Gherkin') in London, which although not an immediate commercial success, has become one of the best addresses (30 St Mary Axe) in London and is recognized worldwide;
- to funders and developers—the balance of risk and reward that outperforms other investments and activities.

Furthermore, the expectation of each stakeholder is liable to change over time, particularly once construction on site begins and the impact of increased traffic to and from the site begins to affect the quality of that location. This then presents a challenge to the developer with regard to continuity and gaining the commitment of the involvement of key project team staff for the duration of the project, thus maintaining, among other things, key interfaces to sensitive relationships.

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5.2 Design challenges

Achieving suitable floorplate efficiencies

Net gross efficiencies are adversely affected by height as core and structural zones expand relative to the overall floorplate to satisfy the requirements of vertical circulation and to resist wind loads. The shape and geometry of the building, while responding to architectural intent, planning and other constraints, need to satisfy the value and cost sides of the development equation. In these respects, 'fat *is* happy'. On the flipside, slimmer STTs are inherently more expensive to build (predominantly because of lateral restraint issues and wall : floor ratios) and suffer from adverse floor areas efficiencies.

A regular building, like a fat one, will be financially 'happy'. Articulation and complexity are a key cost driver, not least because shape influences the structural solution and façade design, as well as the key ratios of economy and value: wall : floor and net : gross.

Achieving an efficient superstructure solution

The superstructure solution—namely structural frame, cores and upper floors—amounts to 15–25% of the overall construction cost in a commercial use STT. It will be defined by the building's shape and massing as much as by its height. The design will determine the weight and therefore quantity of material required to construct the building, which is an important criterion in cost. However, complexity is at least as important, with the number of members, simplicity of connections, ease of fabrication/erection and a host of other factors having a major influence on the cost.

Maintaining core integrity

The layout of the core is critical to the development efficiency and operational effectiveness of a tower, while also playing a significant role in the way the structure copes with wind loads. The key elements influencing its design are:

- The lifting strategy—drives the core size and has a major impact in terms of design on all towers currently in development. One of the drivers is the acceptable period of time for users to get from ground floor to their destination. The ideal solution balances a number of factors such as number of lifts, speed of lifts, group sizes, building zones and the core arrangement, taking into account space usage as well as cost.
- Structural integrity—positioning risers and duct branches towards the perimeter minimizes the number of openings required, thus facilitating services installation and maintenance.
- Wind resistance—lateral restraint systems need to respond to the exponential increase in wind forces with height, and slender towers are particularly sensitive to sway, thus requiring a stiffer structural frame, damping or other strategy. The impact is due to airflow around the building and the drag of the building form. This can be mitigated through manipulation of shape, geometry, surfaces and mass distribution of the form along with the inherent mass of internal fittings such as partitions and ceilings that help dampen this sway.

As such, core design requires the input of a number of disciplines, working together through an iterative process to optimize structural efficiency, lifting strategy, services distribution and so on—with both costs and space-take to be considered alongside performance.

Façade specification and performance

Façades represent a critical element, not only because of their obvious aesthetic qualities (and contribution to environmental strategy) but also due to the large range of costs possible. The principal reasons for cost variation are as follows:

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- The envelope, when expressed as a cost per unit of floor area, is sensitive to changes in wall : floor ratio (which is principally determined by building shape and size of floorplate).
- The range of specification and architectural intents is considerable; routes to cost efficiency include the maximization of off-site prefabrication, simplicity in detailing and a good level of repetition.
- Cooling of the interior can be supported by a façade that enables natural ventilation or mix mode (both natural ventilation and air conditioning). Where naturally ventilated is the predominant mode, the façade can be designed to deal with the high wind pressures at height. In terms of thermal performance, the façade contributes to the controlling heat loss and gain.
- The façade additionally needs to balance the need to allow sufficient light into the building while minimizing glare for both internal occupants and for neighbouring buildings. Acoustically, the façade must isolate noise from the outside and can help control reverberation time internally.

Façade performance should be considered together with the mechanical and electrical systems in forming the building's environmental strategy.

Complexities arising in mechanical and electrical systems design

M&E design issues specific to STTs focus on providing enough capacity for the population density and load characteristics. In addition to maintaining core design efficiency, maintaining hydraulic pressure for both water and coolant requires pressure breaks and multiple plant.

Another significant contributor to the complexity and cost of M&E system design in STTs is the impact of potential tenant enhancements. In conventional buildings this is not usually an issue, as it is often left to the tenant's fit-out cost, provided there is space at roof or basement to provide the extra generation/cooling requirements. Furthermore, this is across a small number of tenants in a multi-let building.

In an STT, retrofitting the distribution infrastructure along with installing a new generator/plant/chiller for one tenant alone is costly. Multiply this by the increased number of tenants an STT supports and the space and distribution premium throughout the building make it unviable. Potential upgrades are achieved by designing in resilience. This contributes to the cost increase in M&E design, but is the only way tenant facilities can be catered for.

6. CONSTRUCTION CHALLENGES

6.1 Maintaining the pace of construction

The pace of construction is an issue that needs to be considered at the very outset and is constrained by the fact that the programme for constructing a tower follows a very specific sequence, i.e. floor by floor. Thus accelerating on site works is not easy.

Consideration of pace forms part of the risk profile of an STT and can be achieved through strategic programming and buildability reviews. These lead to the optimization of the construction process and mitigation of potential sources of delay and disruption.

The floor construction cycle contributes to pace and can be optimized, potentially through the use of standardization and prefabricated components which help minimize the number of trades operating per cycle. Furthermore, concurrent programming of design, procurement and construction activities can achieve acceptable project durations.

The logistics of on-site material supply focuses on providing adequate craneage and hoisting. Coordinating deliveries and craneage slots is essential to maintaining the pace of construction.

In terms of maximizing site labour efficiency, generous hoisting and welfare facilities must be supplied. Investment in sufficient labour resource is also essential and work on a tower enables trades to

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be effectively kept apart, thus increasing efficiency and permitting flooding the site with labour as required.

7. DISCUSSION

STTs pose different questions for those that fund, design, build, own and operate them. For each of these stakeholders there is an inherent motivation for profit, generally led by responsibility to shareholders.

Developing STTs to obtain this profit demands acceptance of higher risks from the outset, largely due to the extended programme. Using the LEP framework to address the breadth of STT project complexities can help to identify distinct areas of risk and means of mediating against them.

The increasing challenge of providing an acceptable sustainability response was merely touched upon and is beyond the remit of this paper. Climate change and its associated legislation is driving change in the construction industry, particularly in STTs, where the opportunity for environmentally driven innovation can offer long-lasting economic, social and environmental benefits. The economic planning and realization of these benefits will be the subject of much future research and development, derived in part from data gathered on STTs being built or nearing completion today, but essentially through the need—and want—to show that tall buildings can be sustainable.

Global economic growth, driven by increasing urbanization and low interest rates, affords the STT sector markets into which to sell. Indeed in certain established cities such as New York and London there is a necessity to build tall in order to balance rising land costs and make full use of available infrastructure. The extraordinary length of programme in STT development and level of investment required, when compared to the rest of the industry, interacts with a range of economic factors to offer higher risks and rewards. While some of these risk aspects are captured in the Skyscraper Index, the reward aspects attract investment from governments and corporations as property continues to outperform the stock exchange as an asset class.

Supply and demand are mediated by regulation and taxes, all of which appear to be flexible when cities sense the opportunity to boost their status and economy through creation of signature STTs. However, regulation of supply appears to falsely inflate prices in central business districts, which adds further validity to the business case for building tall. In addition, the surging popularity of STT construction is increasingly causing upstream supply-side issues. With manufacturers operating to full capacity and a workforce that has not grown as quickly as demand for their services has, risks to programme, quality and consistency are heightened.

It is important to appreciate the influence these global constraints on the demand and supply drivers for STTs have on the viability of an individual project, but it is the delivery drivers such as programme management and the efficiency of the design of STTs that impact directly on individual project economies.

Efficiency of net : gross floor space is key to balancing construction costs and total sales values. STT construction costs are dominated by structure, façade and services. When material quantities and buildability issues dealing with structure, façades and services are integrated and the various options are costed, more cost-effective design solutions can be reached.

8. COST MODEL INTRODUCTION

The data used for the build-up of the cost model is drawn from Davis Langdon projects in London, at various stages of the product life cycle. These include the Leadenhall Building, the Shard at London Bridge, 20 Fenchurch Street, Broadgate Tower and the Pinnacle.

This cost model summarizes the shell and core construction costs for a notional landmark high-rise office building in central London (residential towers offer a quite different cost—and value—profile).

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It totals 97 550 m^2 (1 050 000 ft^2) gross internal floor area over 55 floors (including ground) and three basement levels. It provides a total net internal area of 62 245 m^2.This is predominantly office space, with about 1860 m^2 of retail and food and drink space at the lower levels. It achieves a net : gross floor area efficiency of just under 64% and an above-ground net : gross efficiency of about 68%. The typical floor to floor height is 3·90 m and wall : floor ratio is 0·55 (there are 55 m^2 of façades for every 100 m^2 of above-ground gross internal floor area).

8.1 Exclusions

Unit rates are based on price levels in central London in the first quarter of 2007 for competitively tendered packages under a construction management arrangement—all assuming an immediate start on site. All non-shell and core items are excluded (demolitions and enabling works, external works, incoming services and fitting-out works). Developers' costs are also excluded (professional and statutory fees, taxation, insurances, finance charges, disposal costs), as are the costs of surveys, monitoring works and environmental impact assessments. Also excluded are professional fees, VAT and site abnormals. The rates may need to be adjusted for specification, site conditions, procurement route and programme.

The number and nature of the challenges to developing super-tall towers means that the range of potential costs is large. For example, in central London the influence of town planning and site constraints (as well as market expectations) is a predominant determinant in the array of sculptural forms that are at various stages of the development process. These shapes offer very different architectural and structural solutions. At first quarter 2007, the range of shell and core construction costs for landmark towers in London was £2400–3100/m^2 (gross internal floor area). The cost model shown in Table 1

Table 1.

Element	£	£/m^2	% £
Substructure	20 038 300	205·42	7·65
Frame and upper floors	50 741 800	520·16	19·36
Roof	1 112 500	11·40	0·42
Stairs	2 030 000	20·81	0·77
External walls, windows and doors	48 748 300	499·73	18·60
Internal walls and partitions	7 881 600	80·80	3·01
Internal doors	2 963 000	30·37	1·13
Wall finishes	4 366 200	44·76	1·67
Floor finishes	3 014 900	30·91	1·15
Ceiling finishes	1 598 300	16·38	0·61
Furniture and fittings	3 520 200	36·09	1·34
Sanitary fittings	731 600	7·50	0·28
Disposal installations	1 560 800	16·00	0·60
Hot and cold water installations	1 853 500	19·00	0·71
Space heating air treatment and ventilation	16 583 500	170·00	6·33
Electrical installation	12 779 100	131·00	4·88
Gas installations	97 600	1·00	0·04
Lift installations	18 924 700	194·00	7·22
Protective installations	1 951 000	20·00	0·74
Communication installations	2 829 000	29·00	1·08
Sustainability enhancements	2 000 000	20·50	0·76
Specialist installations	2 829 000	29·00	1·08
Builder's work in connection	1 755 900	18·00	0·67
Preliminaries and on-costs	52 162 257	534·72	19·90
Total shell and core construction cost	262 000 000	2 687	100

Square metre rate based on gross internal floor area.

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attempts to provide a typical cost profile, but where a project falls in the range will depend on its response to the key cost drivers outlined above.

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