Sustainably Tall: Investment, Energy, Life Cycle

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ABSTRACT

The purpose of this project is to provide an interactive platform for clients and design teams to evaluate the consequences of shape, form, and briefing decisions on the energy use, embodied energy, and capital / life-cycle cost of a tall building early in the design process. The Tall Building Simulation (TBS) model is the result of a collaborative partnership between Aedas, Arup, Hilson Moran (HM), and Davis Langdon (DL). This article details both the technical content behind the model and an analysis of the relationships demonstrated by the outcome.

It is estimated that most decisions determining the sustainability of a project are made in the first 1 percent of a project's program, whereas the majority of the information required for sustainability assessment is not usually available or examined until after the concept stage. By this time, most solutions would need design or briefing changes that are too costly to implement.

The model incorporates early stage spatial, mechanical (HM), and structural (Arup) analysis that are linked to cost and life-cycle databases (DL) through a parametric interface designed by Aedas. Its interactive interface is structured to operate at different levels of detail to allow users with varying expertise to analyze and explore alternatives in real time.

The objective with TBS was to distil this expertise into a singular "intelligent" model that demonstrates the interaction of each discipline against the cumulative annual energy and maintenance costs of the building.

Using the TBS model, architects, engineers, and clients can simultaneously explore the impact of typical technical and design decisions on a tall building's energy footprint and its dynamic relationship to cost at the briefing stage. The model also emphasizes known but rarely quantified user impacts such as tenancy types, occupancy, and operating hours to reaffirm the need for buildings to be perceived as an interface through which occupants engage with their environment.

1 INTRODUCTION

An astounding number of tall buildings have been constructed over the past decade. From Dubai to Cartagena, new neighborhoods and cities have been created that are primarily tall building-led, and barely a new urban development happens without the token tower project. The debate about the true sustainability of such tall buildings has become more animated over recent years as people have begun to question both the urban benefits of tall buildings conceived without adequate infrastructure and the claim of their efficiency.

This paper introduces a framework and tool designed to evaluate the impact of design and briefing decisions on the energy footprint of tall buildings. In discussing the key assumptions behind the Tall Building Simulation model, this paper also challenges current briefing and design practice for determining the energy footprint of tall buildings.

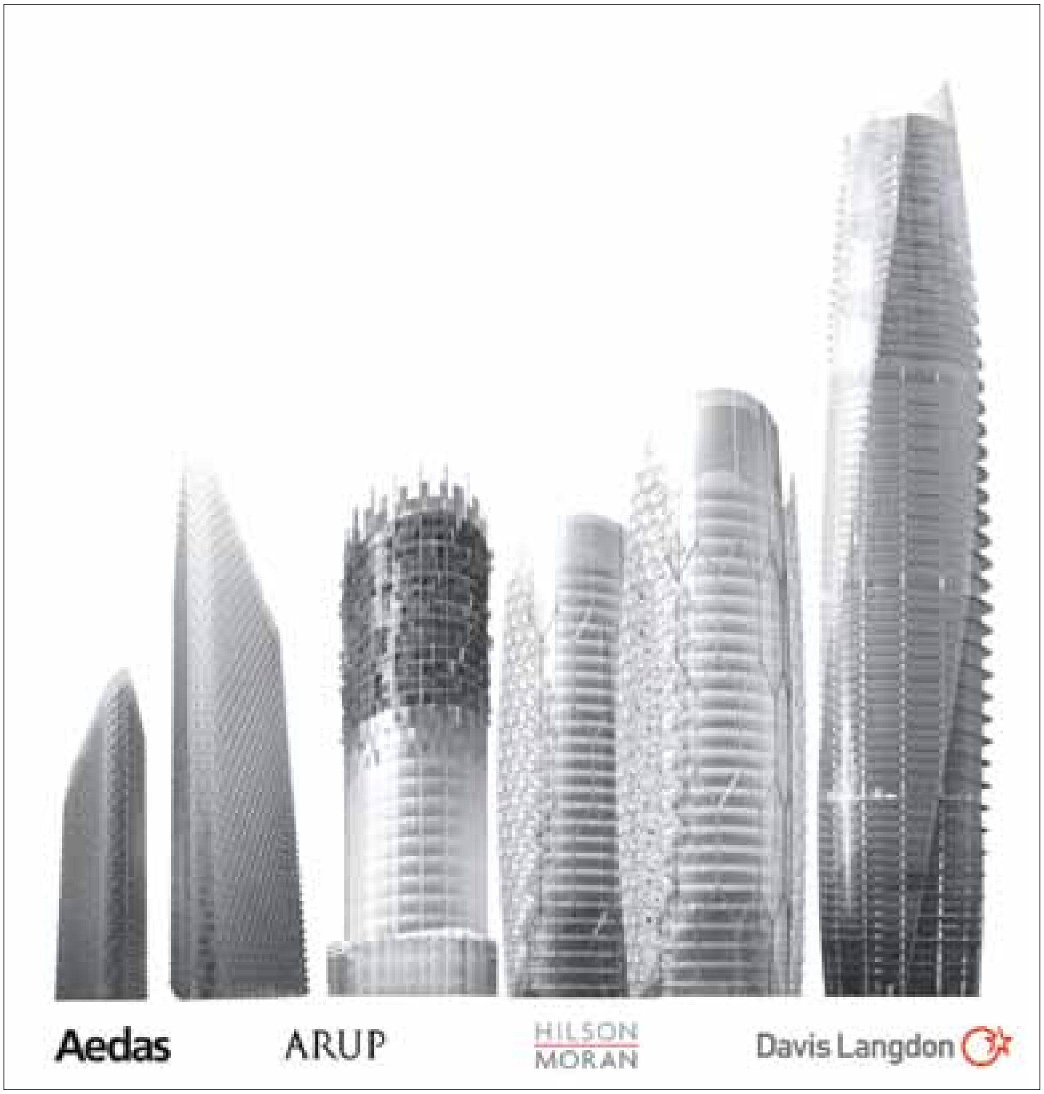
Whilst this project looks specifically at the footprint of a singular building, further research is currently underway that studies the impact of such projects' load on local environmental, social, and transport infrastructures (Deal, 2004).

2 WHY TALL?

Because of the quantities and repetition involved in tall buildings, any efficiencies that can be gained during the design process results in savings of magnitude. The potential gains to be had from sustainable features are, therefore, far greater than for any other building typology. Tall buildings are also highly constrained by structural and other efficiency drivers, which lend this building type well to parametric exploration.

The capital investment and complexity of a tower already requires substantial upfront optimization and prototyping by the disciplines involved. Sustainable design features rely on the integration of such specialist design and technical expertise. The TBS model has made this possible at an extremely early stage.

Figure 1 Examples of Tower Design by Team



3 COST VS VALUE

Members of the project partner group have been involved in the design and construction of tall buildings, with many tall building projects on-site and completed (fig. 1).

Through our collective experience with tall buildings and the implementation and verification of sustainable design features, we have concluded that the way in which building performance is evaluated, particularly during briefing and concept stage, needs to be addressed.

For the past 50 years, building energy use has been firmly in the realm of mechanical engineering. With staff costs amounting to between 80 and 90 percent of a building's annual operating costs, energy use has not featured as part of investment models or architectural expression (Collins 2008). As CO_2 legislation gains momentum across the global community, developers and clients alike are examining the financial incentives for investing capital in solutions that

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reduce the energy footprint of buildings. New research linking higher employee performance to indoor environmental quality and socially and environmentally responsible business practice is having a noticeable impact on client briefing (Kats 2003). Despite the recent drop in oil prices, studies of commercial rental rates have concluded that income from LEED-rated buildings is higher, and has been less exposed to recessionary trends than the rest of the office market (Say 2008; Morris 2007). A tougher regulatory environment and the change of focus in corporate social responsibility towards mitigating climate change—along with fluctuations in energy costs—have demonstrated that energy is an increasingly important factor in the design and commissioning of buildings. This reveals a need for studies that explore the relationship between low carbon designs and their impact on capital and whole-life cost (Eichholtz et al. 2008).

Beyond communicating energy use, a key challenge for the industry has been the lack of data from completed buildings to validate design assumptions and forecast calculations.

4 THE VALUE OF GOOD DATA

Recognizing the significance of having supporting data to argue sustainable design solutions, the team has included real energy use data collected through post-occupancy evaluations and embodied energy figures from recognized sources of data (Anderson and Shiers 2002; Hammond and Jones 2008; Fay et al. 2001). Published research on the energy use of tall buildings were used as benchmark comparisons to verify the outcomes of the model (Collins et al. 2008; Kalita and Watts 2007; CIBSE 2008; Bordass et al. 2000; De Jong and van Oss 2007).

The discrepancy between this data and the predicted energy use that the model serves to highlight is the omission of user impact from the calculations required for regulatory compliance (Approved Document L1A, 2006). Appliance loads, the effects of changes in occupancy, operating hours, and energy intensive functions in the building are not usually part of a building's statutory energy use forecast. By excluding occupant behavior and building management from the realm of briefing and design, we overlook a major contributing factor to building energy use (Bordass 1998).

The interface, as an easily legible dashboard of this quantitative information, has been intrinsic to the model as a design tool to communicate the combined impact of early stage decisions by all parties. The energy bar in particular (fig. 2)

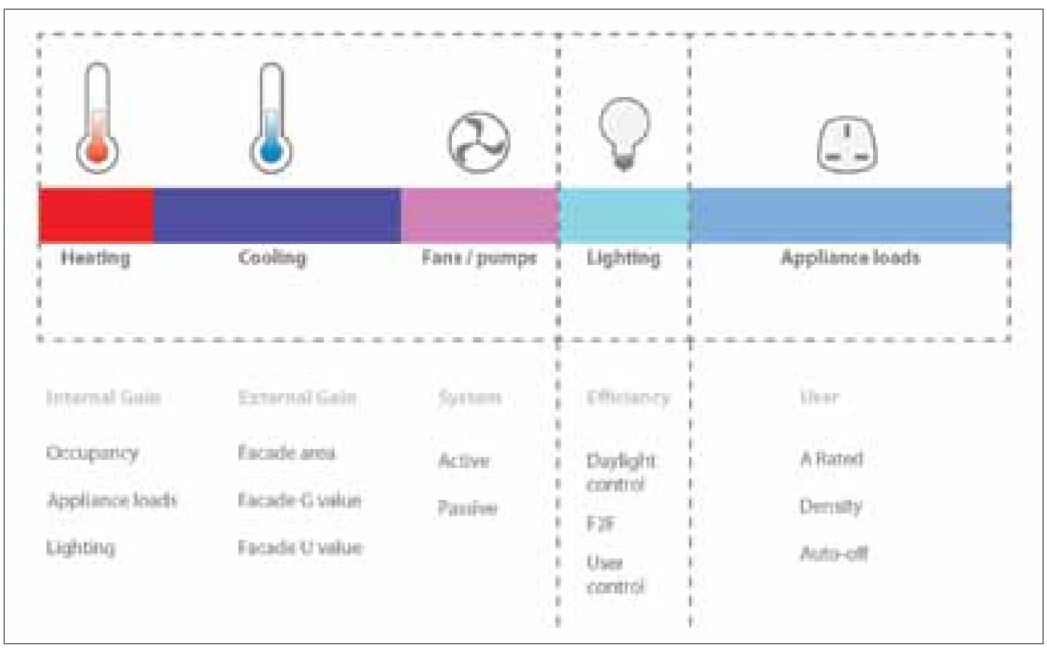


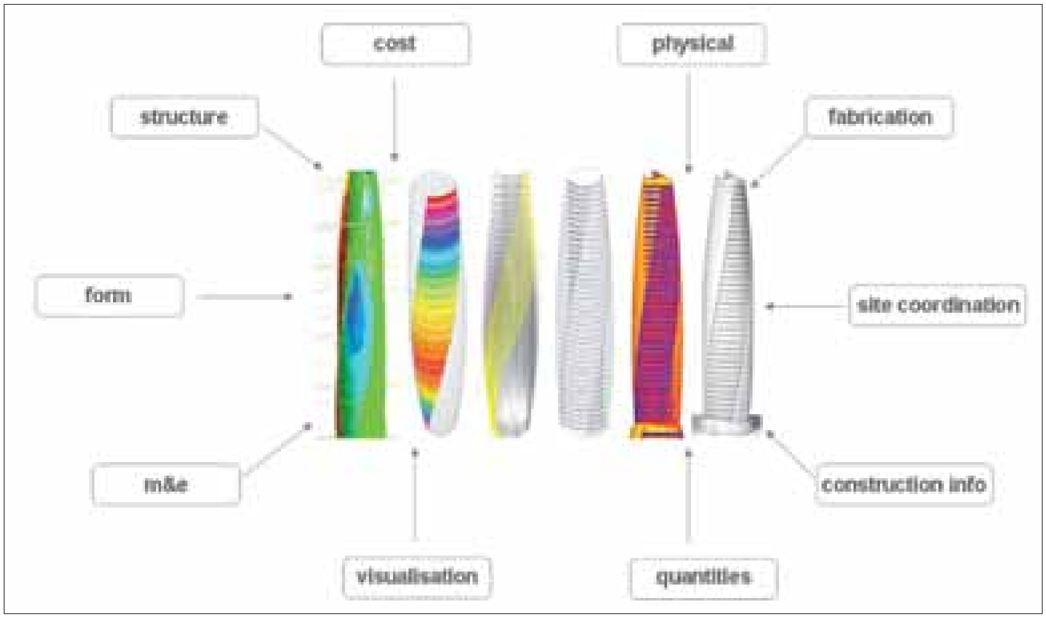
Figure 2 Energy Bar and Color Code

has been adapted from CarbonBuzz (app. 1) to interpret concisely the energy data, as it represents the cumulative outcome of all disciplines.

5 BIM VS. INTELLIGENT MODEL – WORKING ACROSS DISCIPLINES

Successful implementation of low-energy design requires maximum overlap between disciplines during the design process, particularly at the early concept stage. With the development of Building Information Models (BIM), in which all disciplines share 3D information, there is more of an opportunity for cross-fertilization between specialists and their respective silos of expertise. BIM provides the opportunity for extracting quantitative or performance data faster (areas, structural, and environmental analysis), but by the time a model with an adequate level of detail to establish energy use is constructed, it is too late to address many significant drivers such as orientation and massing.

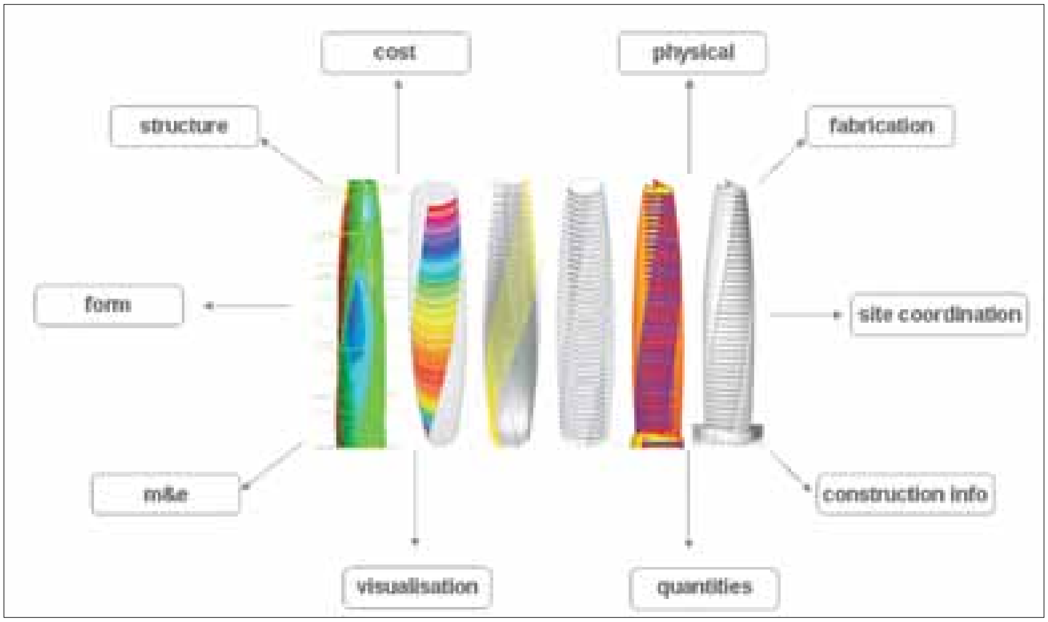
Figure 3 BIM



Recently, platforms such as Generative Components, Digital Project, Grasshopper, and direct script-based solutions have helped designers develop workflows that capture "design logic," (i.e., representations of the spatial and geometric hierarchy of buildings in a lightweight format [fig. 3]).

Alternatively, an "intelligent" model captures a representation of the spatial and geometric hierarchy of a building and utilizes "rules of thumb" to evaluate the model based on underlying relationships, in place of finite element and thermal simulations that are far too intensive for interactive software. In the TBS model, simplified analysis methods from each discipline illustrate in quantitative terms the tacit understanding of leading experts of the workings of sustainable solutions, and predict environmental performance in an early stage, parametric 3D design model.

Figure 4 Intelligent Models



6 METHODOLOGY

In the course of this research, Aedas has led over twenty multidisciplinary workshops with structural engineers and simulation specialists, services engineers, lift consultants, façade consultants, life-cycle assessors, experts in financial modeling, MEP cost consultants, structural cost consultants, and façade cost consultants, as well as architects with many years of experience in delivering tall commercial buildings. The input from these experts was captured and the relationships between disciplines were mapped out in sketches, algorithms, and Excel tables. In creating the Tall Building Simulation model, we have built a spatial "rig"—a 3D parametric model—where the quantitative parameters of

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geometric components are "tagged" and linked to the algorithms describing mechanical, structural, and cost behavior simultaneously. This allows a live update of cost, life-cycle cost, energy use, and embodied energy through a graphic input/output interface.

Taking as a starting point early assessment tools currently in development, the team anticipated that such a model would help highlight some less intuitive relationships behind form, structure, services, cost, and energy footprint, and communicate the most critical areas for a design team to address during the concept and briefing stages (Bordass and Gething 2006).

7 MODEL ASSUMPTIONS

To reduce the complexity of the task, the team constrained the initial model scenarios to the shell and core design of commercial office towers and, using BCO standards as a guideline, simulated only the behavior of tall buildings with regard to their energy footprint (i.e., energy use and embodied energy), against building efficiency capital costs and life-cycle costs. The tower footprint is based on an octagon to simplify not only the mechanical analysis through eight façade orientations but also the structural strategy, by specifying a central core and axial symmetry. The maximum floor plate width and depth has been set to 60 m to accommodate escape distances to a single core, as secondary lift cores would immediately be subject to some notion of design, as the placement and orientation is not defined necessarily by regulation. (For mechanical and structural assumptions, see app. 1.)

8 MODEL SCENARIOS

The most common target at the briefing stage is net achievable area for a particular footprint. If a standard occupancy (14 m2 per person as per BCO guide standards for office areas) and an initial net-to-gross ratio are assumed, the number of occupants can be computed over the gross area of each floor plate. These, in turn, generate values for internal gains, lifts, stair sizes, and plumbing requirements, which determine the plant and riser shaft sizes needed to serve the tower. With the internal requirements of the core set, a structural solution is computed, producing an actual net-to-gross ratio. This figure is then re-used for the next calculation cycle and so on, until the minimum number of floors is achieved for the target net area.

While the structure is dependent on the required area of the mechanical core—to determine core-wall and column dimensions—riser and plant size are likewise dependent on the space occupied by the structure that affects the net area. This, in turn, determines the volume of conditioned air, which will prompt the recalculation of plant and riser size. With any modifications to the relevant parameters, this co-dependent relationship requires solving several iterations to find an equalized result.

Initially, a simple extrusion is generated, after which the model can be manually altered to match different designs and a variety of mechanical, structural, and façade specifications.

In the scenarios below, we have described the typical impact of these specifications on a tall building's CO2 footprint and capital and life-cycle costs. The scenarios also demonstrate how changing these will affect the building's efficiency indicators (net to gross, wall to floor), energy use, and embodied and life-cycle costs.

8.1 OCCUPANCY

Increasing occupancy leads to increased equipment load, internal gains, cooling load, and MEP size, and a reduction in net to gross. The cost of energy increases significantly, adding to the life-cycle cost.

As occupancy increases, energy use grows at a greater rate, suggesting that while area is the standard measure, stating energy use per occupant may also be relevant. Not apparent in the model are the impact of such high densities on productivity, the marketability of the suggested use, and the ultimate impact on the profitability of companies working in crowded conditions, all of which can be explored with further research.

8.2 WIDE VERSUS SLENDER TOWERS

A slender tower demonstrates less efficiency across the board due to a higher wall-to-floor ratio and a lower net to gross. With a larger percentage of structure and, consequently, less net area, the shallower floor plates lead to increased embodied energy per m2, and reduced floor plate efficiency due to the requirements of the lifts, risers, and stairs, preventing the core from shrinking beyond a minimum limit.

Wider towers can be more cost effective by up to 10 percent, as broadening the footprint increases the gross area faster than the façade area, which is the highest cost component by m2. This makes deeper floor plates more efficient, as there is proportionately less façade to install and maintain.

One benefit of a slender tower, however, is that daylight access improves as the distance from the façade to the core decreases, resulting in a greater proportion of Grade A office area. This zone requires no artificial lighting for approximately 50 percent of the year in the UK, which can reduce energy consumption by up to 10 percent (fig. 5).

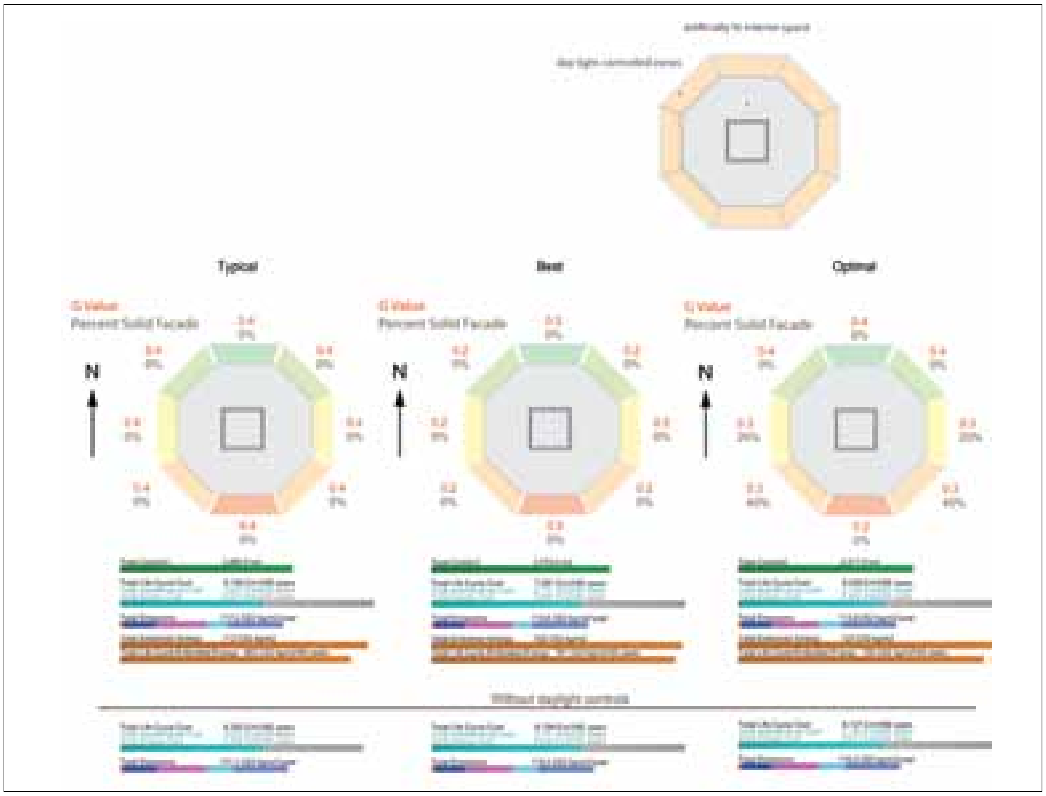

Figure 5 Daylighting and Solar Gain

Although a given shape, form, specification, and life span would suggest an optimum width versus daylight and energy use, the impact of other parameters such as the mechanical system, floor-to-ceiling height, and shape of the building all have to be considered, as many of these systems are determined from the combined demands of several floors. With such benefits achieved through natural lighting, there should be more emphasis on improving daylight penetration and control through design. A future stage of the model aims to take into account the impact of building features such as atria on day lighting and efficiency.

8.3 SHAPE

To illustrate the implications of shape, an extruded tower is compared to two towers of identical net area with inclined and bowed elevations (fig. 6).

Figure 6 Extruded, Inclined and Bowed Elevations

The rotational symmetry of the footprint constrains the center of mass about the axis of the tower. Allowing the core to be off-center would require structural calculations that are more complex. (See app. 1: Model Assumptions.)

Surprisingly, the inclined tower has the best wall-to-floor ratio, approximately 2 percent higher than the straight tower, but requires a broader footprint or additional stories to achieve the same net area. The deeper floor plates at the base offset any savings gained through better daylight access at the top where the tower is narrower. Structurally, it can be assumed that inclined towers require less material due to the effects of wind loading because of their geometry; however, this requires design beyond early concept stage calculations. If we discount the impact of higher heat gains on a tilted façade, form in itself appears to have less than expected bearing on overall energy use and efficiency (fig. 7, 8, 9).

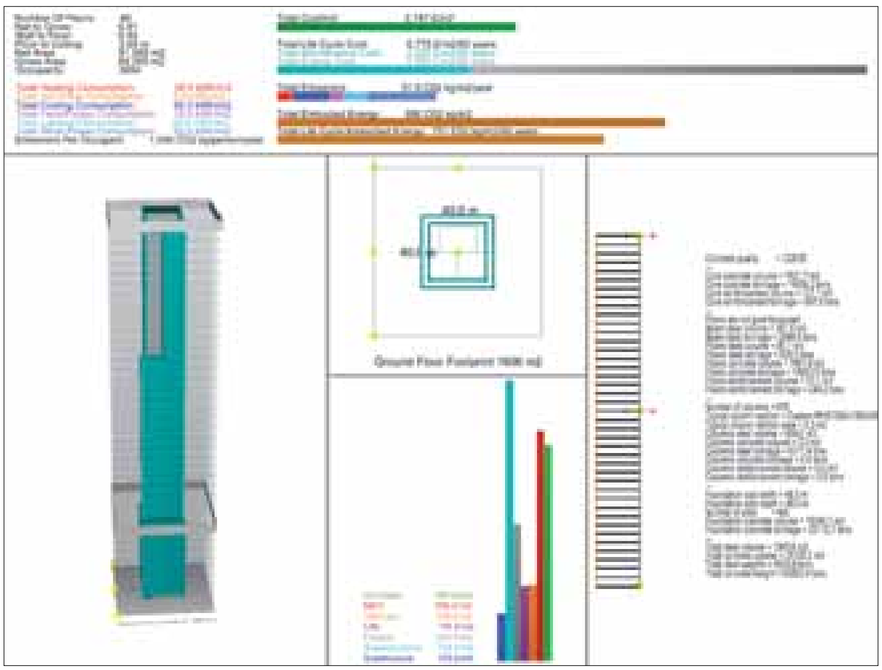

Figure 7 Extruded Tower Form output

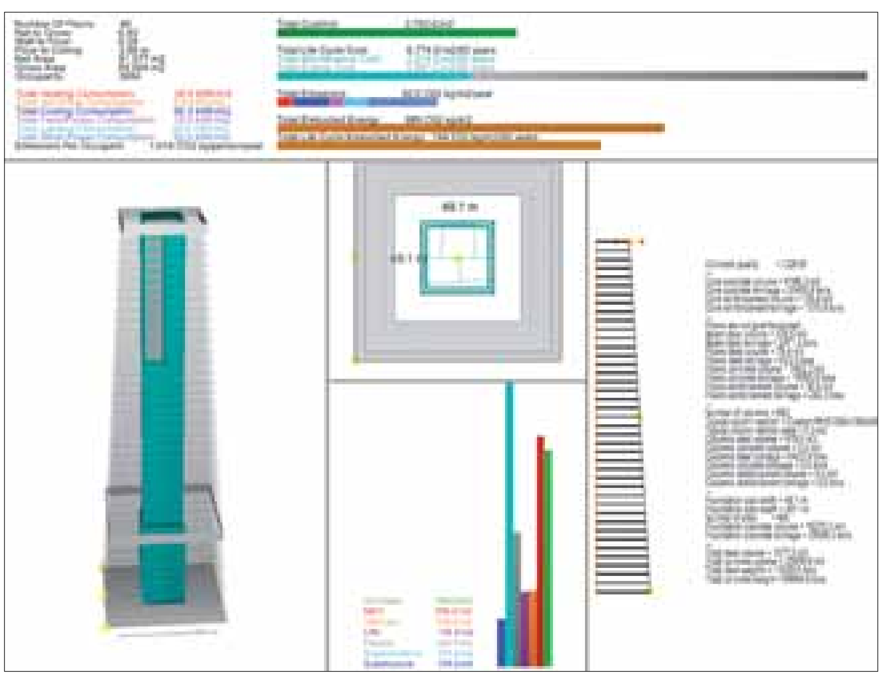

Figure 8 Inclined Tower Form output

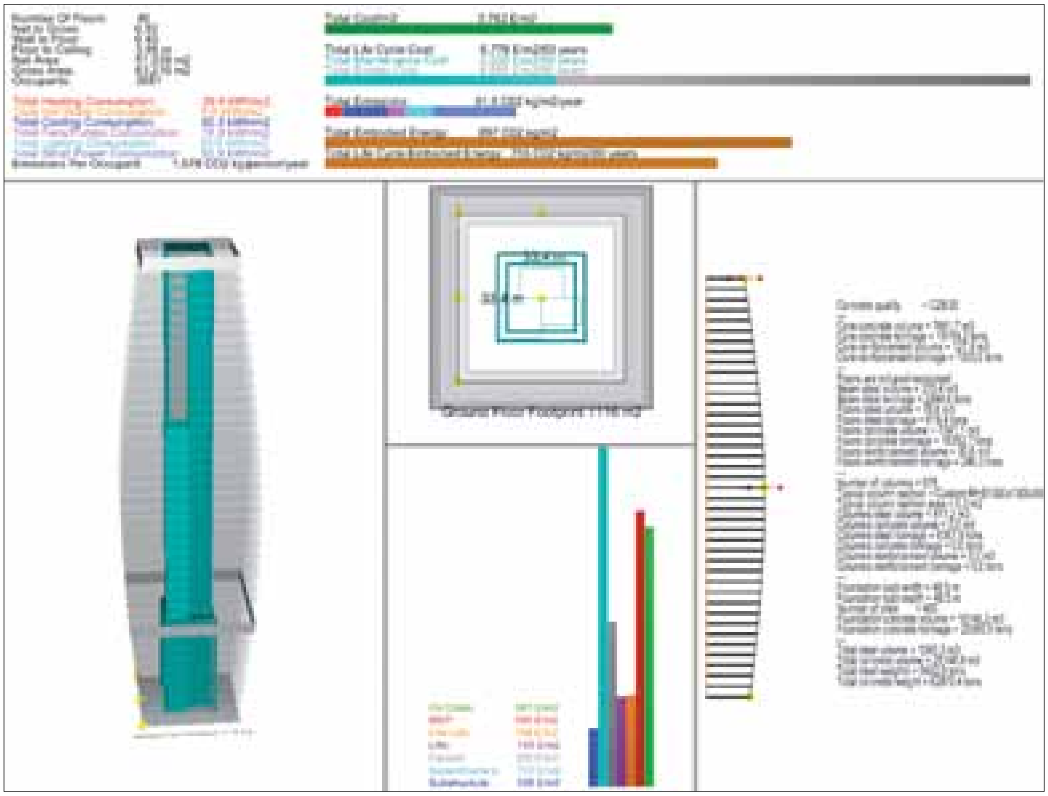

Figure 9 Bowing Tower Form output

8.4 FLOOR-TO-FLOOR HEIGHT

Floor-to-floor height has an impact on daylight penetration and has mechanical repercussions, as it relates to the volume of air per floor. Assuming a constant floor and ceiling build-up, greater floor-to-floor heights substantially increase the volume of material needed to construct the tower (thereby increasing embodied energy). This raises the wall-to-floor ratio and, therefore, capital cost by 5 to 10 percent. The increased air volume per floor results in marginally higher fan loads, which the greater access to daylight offsets straightaway. In practice, the vast cost increase is difficult to justify with improved spatial quality alone. However, beyond a certain floor-to-floor height, natural ventilation/mixed mode becomes an option, even for tall buildings. The authors intend to consider natural ventilation in the next version of this model, and study its impact on key performance criteria, from efficiency to life-cycle cost. With mechanical costs often being responsible for a large part of the operational carbon footprint, the results of this study are expected to be significant.

8.5 ORIENTATION AND CLADDING

The orientation of a building plays a significant role in the cooling loads required to combat heavy solar gain. The trend for tall buildings is to apply a blanket improvement in the G value, which can bring about a 3 to 5 percent reduction in yearly CO2 emissions, with a similar percentage hike in capital cost. A more subtle approach to façade treatments can result in just a marginal increase in capital cost.

Based on studies conducted with our model, a tower with identical façade treatments on all sides, rotated 90 degrees, produces a constant emissions profile, as internal gains from increased solar radiation on the south are balanced by a decrease in radiation from the north. By selecting good solar control for the south façade, increasing the solid areas on elevations facing east and west, and reducing the solar performance of cladding on the north elevation, one can save on capital cost without affecting energy use.

The simulation demonstrates that variation may be employed for function as well as design, and may additionally lower the capital investment when compared to a uniform cladding system.

The complexity of a design (considered as a percent increase in façade length per orientation) affects the exposed surface area of the tower, which contributes to heat gain. Beyond a certain façade performance, however, this is considered marginal in the UK climate, suggesting that although added complexity increases façade cost, this feature has a minimal impact on the building's performance.

8.6 MECHANICAL SYSTEMS

While there are many influences that support the selection of a specific mechanical system over another, the options given in the model attempt to demonstrate the breadth commonly available in the industry. Each system below has individual implications on capital cost, life cycle, and space requirements, in addition to variations in their respective energy profiles. These will have downstream effects on net to gross, life-cycle cost, tenant subdivision, and emissions (see app. 2 for further details). The systems are as follows:

Fan-assisted VAV, displacement ventilation, and fan-coil systems

Water- or air-cooled chillers

With or without heat recovery

For an air-conditioned, sealed tower, specification presents one of the greatest sources of efficiency. With MEP costs accounting for up to one-fifth of a tower's capital cost, as seen from the above studies, the impact of better system specifications over lifetime energy and maintenance costs presents a powerful argument for marginal increases in the capital cost of MEP systems.

8.7 DAYLIGHT CONTROLS

Daylight control systems rely on photosensors that typically operate within a zone 4.5 m from the façade (with greater floor-to-floor heights, the depth of daylight penetration increases), and which automatically turn off perimeter lights at sufficient lux levels. Within the model, a climate data sheet stores average hourly daylight values that relate to the annual natural illumination available. Aside from sky illuminance, time of day, sky conditions, and overshadowing, the required internal lux levels are dependent upon facade length, the floor-to-ceiling height, and the façade specification.

The model demonstrates that daylight controls can reduce energy cost in the range of 5 to 10 percent even in London, suggesting that savings could be even greater in cities with brighter skies. This estimate includes a reduction in any heat gains from the lighting system.

8.8 COOLING / HEATING SET POINTS

Initially set to 23 and 21, respectively, the cooling and heating set points are the temperatures beyond which the temperature control system is activated. By allowing these temperatures to increase and decrease, savings in the range of a few percent can be seen. Hotter climates where air conditioning can account for two-thirds of energy use will see a significantly greater decrease in energy use if the interior is cooled to 25 instead of 23 degrees.

8.9 EQUIPMENT EFFICIENCY

Appliance use (small power) is a much-neglected factor in estimating the real energy use of a building. Set to a starting figure of 25 W/m2 as a combination of appliance density and efficiency, it is multiplied by the daily operating hours and can account for over 50 percent of the energy use of a building. Additionally, reducing the equipment heat gain will reduce the cooling demand, but will also increase the demand for heating during the winter. Limiting tenants' choice to A-rated appliances should be discussed at the briefing stage, along with other measures that raise user awareness of the energy use behind everyday activities.

8.10 HOURS OF OPERATION

Increases in energy use are also attributed to extended hours of operation because of the internal gains from the hours of additional equipment load, occupancy, and lighting loads. This reflects the energy use of many buildings running at a significantly higher cost than anticipated. If operating hours are considered at the briefing stage, then controls and zoning of systems and spaces can be considered accordingly. Incorporating managed hours of use in tenancy agreements is currently being successfully piloted by leading commercial landlords.

8.11 CARBON FACTOR

Carbon factor, the multiplier used to convert energy use to CO_2 emissions, depends on the emissions created at the point of generation and any losses through transmission. Changing the carbon factor allows users to set the energy source to any fuel type, including renewable energy sources.

CONCLUSIONS

Designers are often reluctant to get involved in the analysis of building performance, partly because of its technical nature, and partly, perhaps, because this is perceived to be the realm of specialist engineers who are expected to find solutions to performance issues. Energy use in the past has been considered a mechanical issue, yet this paper suggests that architects have a significant influence.

The team has found that well-integrated solutions bring the greatest benefits to the energy performance of tall buildings.

Sophisticated façade solutions can be wasteful without the analysis of orientation, together with the mechanical system employed; the benefits of good daylighting can be ineffective without appropriate control systems. Natural ventilation in itself requires a particularly detailed coordination of all disciplines, as it requires façade and control systems that are more costly, and could alter the building's geometry and efficiency, but it can significantly reduce the size of the mechanical system. More research is needed to quantify the trade-offs.

Collaborative thinking is equally essential to address occupant energy use and user engagement, which typically account for a third of a tall building's energy use. Restricting hours of use, reconsidering the cooling and heating set points, and improving the buildings management system through staff training can reduce energy use without using additional resources. Briefing requirements such as added resilience, specific tenancy arrangements, and preferred ventilation systems also have a major impact on energy performance, as well as on capital and whole-life costs.

Structural performance was found to have little impact on operational energy use. Nevertheless, it is the largest contributor to the embodied energy of a shell-and-core solution—internal finishes can have a greater impact over the lifetime of the building. Some of the most influential structural drivers in defining the parameters of a tall building were outside the remit of standard structural optimization. When the model was piloted in alternative locations, the availability of materials, labor constraints, and local construction techniques greatly influenced the choice of structural systems.

The authors are still in the process of validating the model against data from initial benchmark projects, but this model has already helped communicate some essential steps for any design team (app. 3). All participating teams are set on collecting more data on completed buildings to verify increasingly complex design scenarios against the model.

A remarkable outcome of the Tall Building Model is that, despite the technical nature of the topic, clients and designers who typically do not engage at this level were able to gain rapid insight into the underlying performance drivers of tall buildings. Use of the model in live briefing and design situations has inspired creative input from across disciplines.

CONTRIBUTORS

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APPENDIX 1. CARBONBUZZ

Aedas has, over the past three years, embarked on a practice-wide strategy to monitor the effectiveness of sustainable design solutions from design to operations. The practice offers post-occupancy evaluation to all clients as a matter of course, and contrasts design with actual measurements of building performance (Aedas Green Book and Green Tool AJ Honorable Mention 2008).

As the information gathered was collated, a dialogue between disciplines emerged to understand some of the reasons behind the discrepancy between design and actual performance. This led to the development of other cross-disciplinary initiatives, such as the CarbonBuzz project, which is the first collaboration between the RIBA CIBSE on sustainable design. The online platform allows designers to monitor, benchmark, and share energy use information of projects from design to operation (Aedas app.).

The CarbonBuzz project has contributed to broader industry recognition of the lack of data available in the public domain (UKGBC comments, AJ, CIBSE, Building Design articles) to benchmark, assess, and verify project sustainability performance, even when examining the most regulated indicator, energy use. This realization has since fed into the development of the UKGBC's Code for Sustainable Buildings Task Group report, which aims to provide clarity on how to improve the sustainable performance of projects from acquisition to end of life, covering all building types from large-scale master plans to refurbishments. A key proposal of this report is for the UK government to publish data relating to sustainable design performance, to enable research and benchmarking to take place in the construction industry. Without this data, we will continue to lack the evidence necessary to support changes in legislation, and the true environmental impact of the buildings we occupy will remain restricted to the specialists.

APPENDIX 2. MODEL ASSUMPTIONS

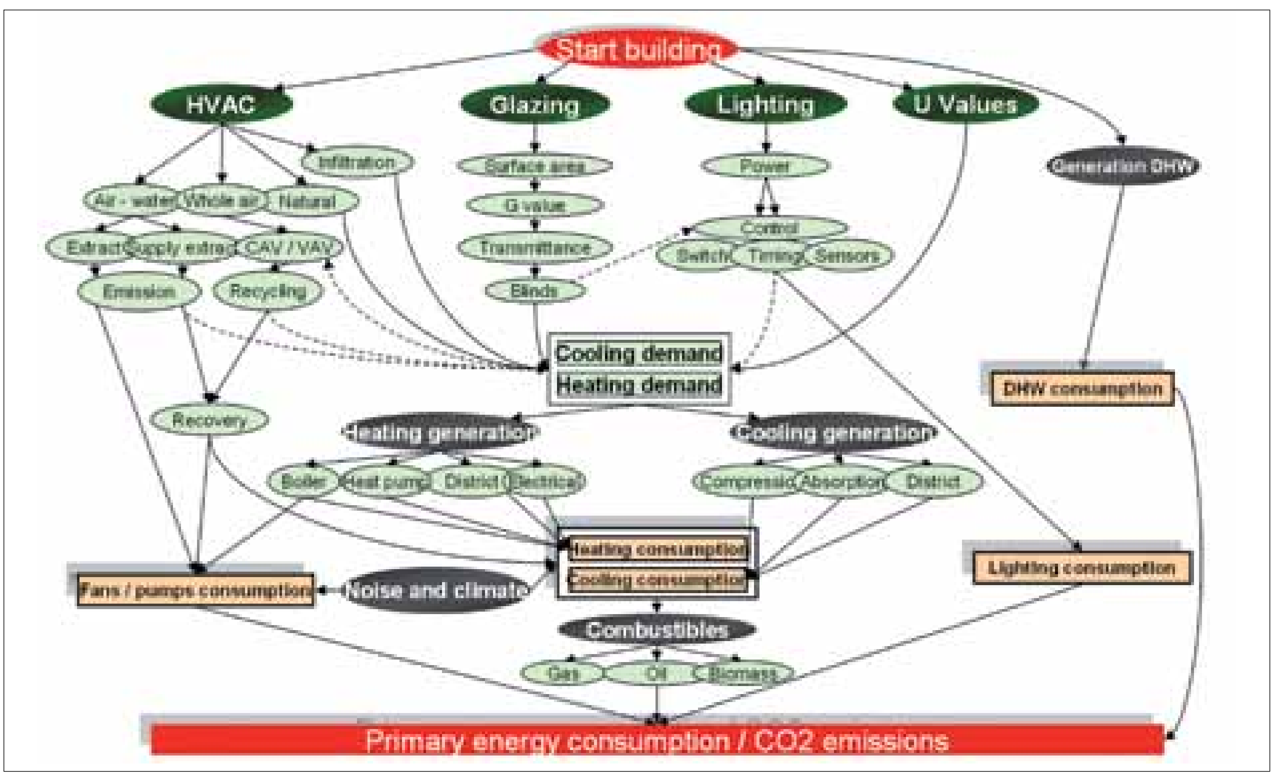
DAN JESTICO – Hilson Moran:

Building services engineers are increasingly involved with the early stages of building design to optimize architectural form, with the aim of reducing energy usage and associated CO2 emissions. When sustainability is considered at the project outset, the greatest gains in energy savings are possible at the lowest cost.

The input from Hilson Moran to TBM can be broadly broken down into five areas:

Lift strategy
Energy consumption and CO2 emissions
Savings due to daylighting

Figure 10 MEP Interrelationship of Variables



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Plant area requirements
Riser area requirements
In order to integrate these areas into TBM, it was necessary to utilize the skills of mechanical engineers, electrical engineers, vertical transportation engineers, environmental engineers, and sustainability consultants.

Based on the population, an approximation of the number of passenger lifts required was further subdivided into groups of eight lifts, with each group of lifts serving as a separate, vertically stacked zone. Goods and firefighter lifts, based on institutional and UK building code requirements, supplemented the passenger lifts. The area required for the lifts was used to define the core size and, hence, drove the iterative process of defining the building height required to obtain the desired internal area.

The energy and emissions modeling for TBM was initially investigated by working backwards from the final output figures, given in kg CO_2/m^2 per annum. The number of input variables affecting this figure was considerable, as shown in the diagram (fig. 10).

The output from the energy modeling falls into five main categories:

Heating
Cooling
Fans and pumps
Hot water
Lighting
Equipment (not shown in previous diagram)

The hot water and equipment consumption are a direct function of the occupation density and, therefore, relatively easy to calculate, based on the model inputs. Where daylighting controls have not been included, the lighting load is also a direct function of the initial data input to the model.

The heating and cooling demand loads are a function of many different aspects of the building design, all of which are interrelated. For example, reducing the equipment heat gain will reduce the cooling demand, but it will also increase the demand for heating during the winter. The most important aspects are listed below.

Facade glazing G value
Floor-to-floor height
Facade percent glazing
Total internal heat gains due to occupancy, lighting, and equipment
Heating set point
Cooling set point

The final energy consumption (and hence emissions) due to heating, cooling, and fans and pumps is then an additional function of the building HVAC system selected.

In order to calculate the heating and cooling demand figures, it was necessary to define one equation that would generate the demand given the six inputs listed above. The equations for heating and cooling for eight different facade orientations and an internal space were assumed linear for reasons of time and simplicity. Although tests on the resulting equations showed that relationships were not strictly linear, the differences were small given the overall impacts of the changes being studied.

In order to define the 126 coefficients required for the 18 equations, results from 126 experiments were obtained using Dynamic Thermal Modeling (DTM). DTM consists of a transient computational simulation, which utilizes real weather data on an hour-by-hour basis. Variables such as external temperature, wind speed and direction, solar radiation, cloud cover, and humidity are used in conjunction with the building's material construction and internal heat gains to provide results on the internal temperature, heating and cooling loads, and the amount of airflow through study zones.

The annual heating and cooling demand can now be defined for each of eight façade orientations, plus the interior on a kWh/m^2 basis. This information was then used to define the annual energy consumption of gas and electricity, which is dependent on the building HVAC system type. For the tool, the most common systems from the energy flow diagram have been used. These are:

Fan-assisted VAV, displacement ventilation, and fan-coil systems
Water- or air-cooled chillers
With or without heat recovery

Although at this time, the number of systems is limited to three different HVAC system types, the intention is to develop the tool to incorporate other systems, such as active chilled beams.

Typical system efficiencies of the various system types are used to convert demand figures into consumption figures. The consumption figures can then be converted into annual CO2 emissions, using conversion factors dependent on the fuel used and electricity grid emission factor. Daylight modeling has also been employed to predict the annual energy savings possible with daylighting controls. The zone daylight factor is calculated from the following inputs:

Daylighting zone depth from facade
Daylighting zone width
Floor-to-ceiling height
Facade percent glazing
Facade percent frame
Glazing percent light transmission

The daylight factor is compared to the required external luminance to calculate the percent savings in daylighting for each zone.

The effect of riser and plant space requirements on the building area efficiency was defined using a sliding scale between the minimum and maximum percentages of floor area required, based on previous project experience. User choices based on various servicing arrangements, HVAC system selection, and required levels of resilience are scored depending on the relative amounts of area required. These scores are then totaled and used to define the percentage area required by both plant and risers.
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The structural performance module generates a structure based on various measurements and characteristics of the building, and on information on its environment, estimated dimensions for structural elements, and finally, estimates and outputs of material quantities required for the structure. However, these are not presented to the user, as they are not part of the key performances of a building; rather they are woven back into the model to influence other performance indicators such as cost and embodied energy. Furthermore, the structure has a large impact on the net-to-gross floor area ratio, as mainly the core dimensions impact the available floor area to the user.

The structural performance module uses a variety of techniques to estimate the core dimensions, from rules-of-thumb to analytical mechanics, as well as optimization and structural code-checking formulas. The estimates have been made with the idea of "optioneering" in mind, which indicates a phase in the building design before design. The Tall Building tool will never to able to produce a fully optimized engineered design, as this would require detailed exception possibilities to optimize the performances. Such optimization grows rapidly in complexity, which current computation is not able to deal with. Therefore, the user has to keep in mind that a certain amount of inaccuracy exists with the results of the tool.

The structural performance module has a variety of inputs. The general module provides the building dimensions as well as measurements of the floor slabs and grid sizes (primary and secondary spans between columns). Furthermore, the use of each floor needs to be defined. The user is then able to select two structural types. Both include a central concrete core. One is composite floors with steel beams and columns, and the other is concrete flat slabs with concrete columns, with optionally post-tensioning of the floors.

The structural performance module provides volume and tonnage information for steel, concrete and reinforcement quantities. These outputs can be totaled or split between the different parts of the model: floor slabs, beams, columns, core, and foundation structure (fig. 11).

APPENDIX 3. NOTES FOR BRIEFING

Consider designs that address user behavior and make the building easy to use and operate.

Forecast energy use to include occupant density and likely operating hours.

Structural options should assess embodied energy per net area, and any solutions such as post-tension floors that increase floor-to-ceiling height while lowering the floor-to-floor height. Optimize column spacing.

Specify cladding systems depending on orientation. Some obvious solutions for London include a high percentage of solid glazing on east and west facades, triple glazed or louvered treatment on the south, and improved U values for full transparency on the north façade.

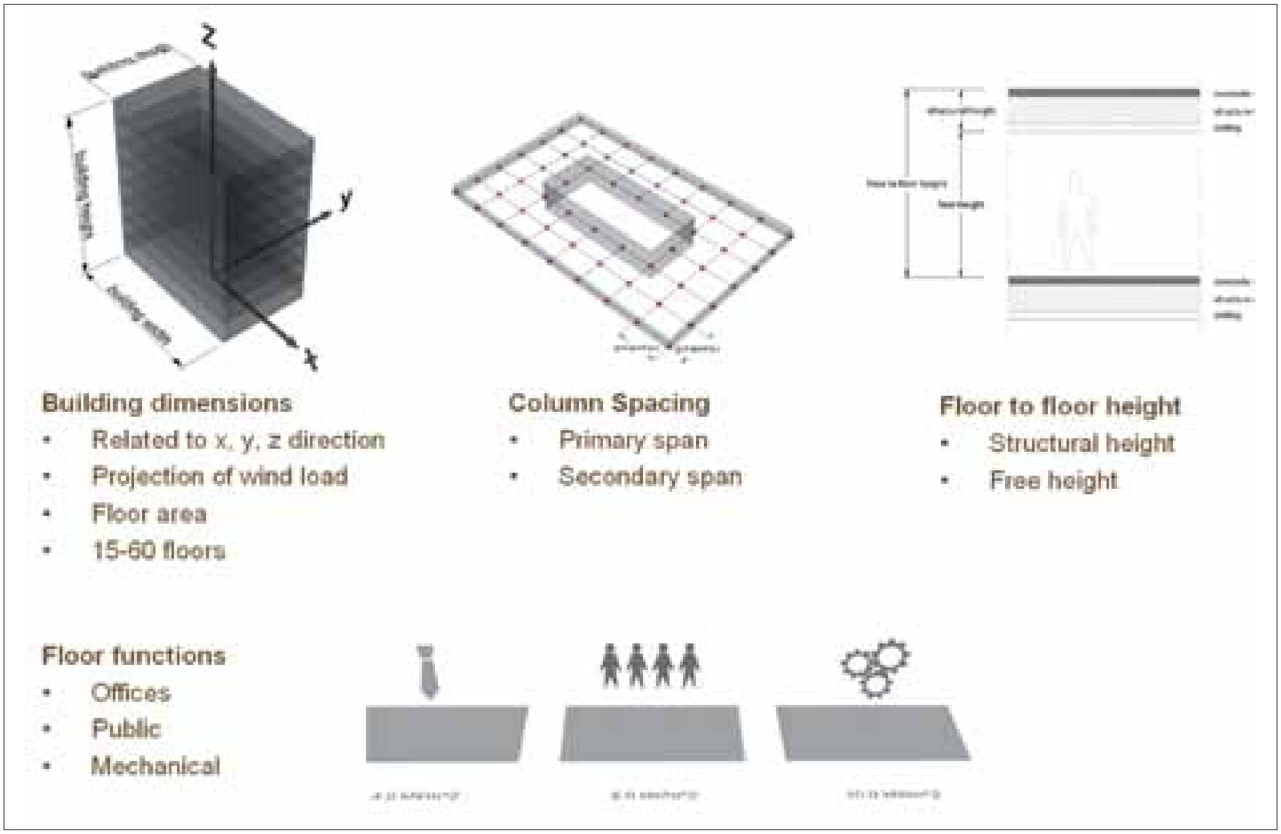

Figure 11 Structural assumptions

Evaluate the spatial and energy use consequences of mechanical systems.

Agree with client and include in Building Manual the requirement of A-rated appliances with controls by zoning, timers, or other sensors.

Include daylight sensor systems and zone lighting parallel to the building perimeter.
Agree on a change of design criteria to allow user control of heating and cooling set points.

Evaluate the appropriate daily hours the building will be in use. Underestimating can lead to a less efficient use of the system specified in view of the complete energy profile of the building, including occupant energy use.

Explore the potential of renewable energy and the impact this can have on the emissions and cost of energy.

Incorporate sub-metering and energy use displays in the building to monitor performance.