Design Challenges of Tall Buildings and Implications on Construction Education

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Abstract
As the world economies continue to expand, building designers are faced with the challenges of leading future development that meet the need of occupant comfort, safety, building protection as well as conservation of the environmental quality in the built environment. For tall building design, these developments entailed a multi-disciplinary effort, where designers must understand how their efforts integrate with other design team members to provide an overall project that is attractive, cost effective, energy efficient and flexible in meeting the needs of occupants. In these regards the designer’s understanding of the whole building system are crucial therefore the necessity for a multi-disciplinary education to ensure effectiveness in carrying out the design processes and implementations. This paper reviews and discuss the design considerations for enhancing performance in future tall buildings in the context of sustainability and safety/security. Their impacts upon construction and design educations were discussed. The development of education to cater the needs of whole building design approach and collaborative learning to foster better understanding, communication and team working in tall building design were emphasized in preparing students (future designers) to meet the demands of rapidly changing design and construction industry.

Keywords: Tall buildings, Performance, Design education, Sustainable, Whole building design

1. Introduction
Tall buildings in city centres continue to be the idealistic concept of living and working in close proximity. For occupiers, it provides a solution for a better workplace and residential in an urban environment accommodating comfort and convenience of modern demands. For developers and investors, tall buildings will maximise potential land values and offer long term investment growth since the building’s image means that potential tenants tend to be strong covenants. The buildings also tend their positive image to developers who are associated with building prestige developments.

For investors, tall buildings potentially bring important strategic advantages to cities, dispensing status and recognition on the city, and meeting market demands for space. They act as a catalyst for urban regeneration, attracting inward investment, generating jobs and tax revenue.

As the world economies continue to expand and the demand of tall building increases, building designers are faced with the challenges of leading future development that meets the need of occupant comfort, security, safety, as well as conservation of the environmental quality. Thus the advent of sustainable / high performance building that looks into every aspects of design to deliver superior energy, economic and environmental performance to their occupants and owners, as contrast to in the past where the primary design concern lies mostly in the operational efficiency. Builders and developers benefit from their investment in sustainable buildings with the increase of the building’s appeal and marketability.

In the 1990’s the development of tall office buildings concentrated on sustainable design. However, to some extent, the confidence of developers, insurers
and tenants were shaken by 9/11 incident and tall buildings faced scrutiny with regards to its structure and life safety designs. These have caused building owners, occupants and designers to pay more attention to facility security and safety issues. The emphasis on special design features to limit progressive collapse, to provide the necessary fire protection, emergency egress facilities, building security as well as other safety aspects to enhance the building’s emergency performance are now given more consideration by designers.

For tall buildings to continue and to serve the urban community as in the past it is essential for designers to rebuild the confidence of occupants and investors through safe design provisions but without compromising on economics and environmental issues. These new requirements which balances sustainability and safety/security are one of the design challenges for future tall buildings. The paper will address these design requirements and discuss their implications on existing construction education in meeting the changing needs of the industry.

2. Design considerations for tall buildings
2.1 Sustainability
The main goals of sustainable design are to avoid depletion of resources including energy, water, and raw materials; prevent environmental damage caused by buildings and facilities throughout their life; and create building environments that are liveable, healthy, and productive. A sustainable building design is based on the following objectives: Optimize Site Potential, Minimize Energy Consumption, Protect and Conserve Water, Use Environmentally Preferable Products, Enhance Indoor Environmental Quality (IEQ) and Optimize Operational and Maintenance Practices.

2.1.1 The Site
A proper site selection includes consideration of the reuse or rehabilitation of existing buildings. The location, orientation, and landscaping of a building affect the local ecosystems, transportation methods, and energy use. The selection for site for physical security has also become a critical issue in optimizing site design. For tall buildings its ability to minimise the impact on land use and cost of land by building upwards is one of the main drivers for future demands. Developing a brownfield site for tall buildings will improve sustainability whereas construction build on a greenfield site is regarded detrimental to the surrounding landscape. It may well be argued that a brownfield site is likely to be more costly to develop but on the other hand, may provide substantial cost savings in terms of existing provision of public transport networks and parking spaces. Constructing on brownfields site however, imposed several challenges such as constraints on construction process like accessibility and congestions for materials delivery (Pank et al. 2002). The location of tall buildings within an urban area determines the amount of daylighting and may even create wind tunnels. A good design from a holistic perspective at the conception stage is therefore essential to overcome these possible problems.

2.1.3 Minimize Energy Consumption
A building should rely on conservation and passive design measures rather than fossil fuels for its operation. Energy efficiency is a key element to tall building design. The need to install elevators in tall buildings will increase energy demands but day lighting potential is better than in low-rise deep plan buildings. There are always trade-offs between different environmental considerations associated with supplying the energy used within the building, but low energy use is a fundamental key to sustainable development. The key to zero carbon dioxide (CO2) emissions means the ability to create own energy on site (Pank et. al, 2002). Renewable energy sources from solar and wind provides alternatives to low energy use.

2.1.4. Protect and Conserve Water
Fresh water is an increasingly scarce resource. A sustainable building should reduce, control, or treat site-runoff, use water efficiently, and reuse or recycle water for on-site use when feasible. Practical considerations for water conservation techniques include rain water collection, low flow wash hand basins, dual flow WCs and gray water recycling.

2.1.5. Use Environmentally Preferable Products
A sustainable building should be constructed of materials that minimize life-cycle environmental impacts such as global warming, resource depletion, and human toxicity. In a materials context, life cycle includes raw materials acquisition, product manufacturing, packaging, transportation, installation, use, and reuse/recycling/disposal. The selection of materials for tall buildings lies in its functionality. Materials with modular components, reduces time on site and development cost and therefore considered sustainable. The use of recycled materials and standard size materials (which reduces waste) improves sustainability.

2.1.6. Indoor Environmental Quality
The indoor environmental quality (IEQ) of a building has a significant impact on occupant health, comfort, and productivity. Among other attributes, a sustainable building should maximize day lighting, have appropriate ventilation and moisture control; and avoid the use of materials with high volatile organic compound (VOC) emissions. Additional consideration is now given to ventilation and filtration to mitigate chemical, biological, and radiological attack. Integrated design and
the use of structural materials for optimum performance in controlling the internal environment of buildings can provide added benefits at no cost. The selection of facade materials can greatly influence the thermal performance of buildings. As methodologies for the life cycle assessment of cladding materials develop, awareness is growing of their environmental impact among designers and specifiers.

2.1.7 Operational and Maintenance Practices
Incorporate operating and maintenance considerations into the design of a facility will greatly contribute to improved working environments, higher productivity, and reduced energy and resource costs. Designers are encouraged to specify materials and systems that simplify and reduce maintenance requirements; require less water, energy, and toxic chemicals and cleaners to maintain; and are cost-effective and reduce life-cycle costs.

2.2 Safety and Security Issues
Designing and constructing safe and secure have always been primary goals for owners, architects, engineers, and project managers, there is increased concern on these issues for tall buildings after the 9/11 incident. Designing for natural disasters, acts of terrorism, indoor air quality, materials hazards, and fires, a multi-hazard approach are vital towards building design that accounts for the potential impacts of major hazards.

Whole Building Design Guide (WBDG) identify four fundamental principles of multi-hazard building design:

Plan for Fire Protection
Planning for fire protection for a building involves a systems approach that enables the designer to analyze all of the building’s components as a total building fire safety system package.

Ensure Occupant Safety and Health
Some injuries and illnesses are related to unsafe or unhealthy building design and operation. These can usually be prevented by measures that take into account issues such as indoor air quality, electrical safety, fall protection, ergonomics, and accident prevention.

Resist Natural Hazards
Designing against natural hazards will reduce the risk of buildings from damaged.

Provide Security for Building Occupants and Assets
Effectively secure building design involves implementing countermeasures to deter, delay, detect, and deny attacks from human aggressors. It also provides for mitigating measures to limit hazards and prevent catastrophic damage should an aggressor be successful. Through comprehensive threat assessment, vulnerability assessment, and risk analysis, security requirements for individual buildings are identified, and appropriate reasonable design responses are identified for integration into the office building design. Following the WTC incident and other attacks on tall buildings, the vulnerability to this kind of attack has been highlighted and become new issues for designers to face. With lessons learned from the World Trade Centre tragedy, safer design to facilitate egress in tall buildings and avoid progress collapse of buildings have been emphasized (FEMA, 2002)

2.3 Security / Safety and Sustainability Synergies
Environmental concerns in the built environment have made sustainability an increasing priority for facilities projects. However, the events on September 11, 2001 have caused building owners and occupants to pay increased attention to facility security and safety issues. The iconic value and physical vulnerability to attack has led to serious security concerns in tall buildings since the World Trade Centre incident.

At the surface, it may appear that secure/safe design has very little relationship to sustainable design. Yet, security and safety measures, such as those for anti-terrorism must be considered within a total project context, including impacts on occupants and the environment irrespective of the level of protection. Hence, it is necessary to provide designers with an understanding of the interaction between security/safety and sustainability objectives. Through the whole building design process, areas of synergy and conflicts between the two approaches can be identified thus allowing sustainability opportunities within certain security/safety strategies to be highlighted. Upon acquiring this information, the project team can then define and understand better the interrelationships between the project’s needs and achieve balanced design solutions that will minimize environmental impacts as well as ensuring health, safety and comfort of building occupants.

With a given budgetary and other constraints, integrating secure/safe and sustainable design objectives may require compromise and trade-offs. Conflicting objective will pose challenges to the project team in finding creative solutions to a particular problem. Examples on safety strategies and sustainable opportunities extracted from the Whole Building Design Guide (WBDG, 2001) are listed in Table I
Table 1. Sustainable design considerations and opportunities when employing various safe design strategies.

<table>
<thead>
<tr>
<th>Safety and Security Strategies</th>
<th>Sustainable Design Considerations/Opportunities</th>
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<tbody>
<tr>
<td><strong>Access Control</strong></td>
<td></td>
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<tr>
<td>Secure site perimeter</td>
<td>Integrate with sustainable landscaping scheme</td>
</tr>
<tr>
<td>Use barriers to prevent passage of vehicles</td>
<td>Use natural and/or environmentally friendly barriers (e.g., trees, retention ponds, recycled-content planters, etc.)</td>
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<tr>
<td>Minimize public entrances into the building</td>
<td>Integrate with daylighting scheme</td>
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<tr>
<td>Secure vulnerable openings (e.g. doors, first floor windows)</td>
<td>Integrate with daylighting scheme</td>
</tr>
<tr>
<td>Install electronic access systems (e.g., parking, elevators)</td>
<td>Use energy-efficient systems. Consider renewable and/or distributed energy resources</td>
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<tr>
<td><strong>Surveillance</strong></td>
<td></td>
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<tr>
<td>Place windows and doors to allow for good visibility</td>
<td>Integrate with daylighting scheme</td>
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<tr>
<td>Avoid blocking lines of sight with fencing and landscaping</td>
<td>Integrate with landscaping and daylighting schemes.</td>
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<tr>
<td>Install intrusion devices and video systems</td>
<td>Integrate with building automation and control systems. Use energy-efficient lighting and controls. Consider renewable and/or distributed energy sources</td>
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<tr>
<td><strong>Blast Protection</strong></td>
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<tr>
<td>Design structural systems to prevent or delay building collapse</td>
<td>Integrate with passive solar design (e.g., Trombe walls). Use sustainable materials (e.g., fly-ash concrete, slag concrete, steel columns, etc.)</td>
</tr>
<tr>
<td>Use building configurations to better resist blast shock waves</td>
<td>Integrate with passive solar design and daylighting scheme</td>
</tr>
<tr>
<td>Maximize distances between parking and buildings</td>
<td>Integrate with alternative transportation plans</td>
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<tr>
<td>Size and locate windows with detonation points in mind</td>
<td>Integrate with daylighting scheme</td>
</tr>
<tr>
<td>Increase strength of exterior cladding and non-structural elements</td>
<td>Use sustainable materials. Consider thermal benefits of strengthened cladding options</td>
</tr>
<tr>
<td><strong>Chemical, Biological, Radiological Protection</strong></td>
<td>Consider dedicated ventilation and/or exhaust systems</td>
</tr>
<tr>
<td>Elevate fresh air intakes</td>
<td>Integrate with energy-efficient HVAC system</td>
</tr>
<tr>
<td>Apply external air filtration and over-pressurization techniques</td>
<td>Integrate with building automation and control systems</td>
</tr>
<tr>
<td>Use internal air filtration technologies</td>
<td>Integrate with building automation and control systems</td>
</tr>
<tr>
<td>Secure vulnerable areas (e.g., mechanical rooms, storage)</td>
<td>Consider dedicated ventilation and/or exhaust systems</td>
</tr>
<tr>
<td><strong>Energy Security</strong></td>
<td></td>
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<tr>
<td>Create redundant systems</td>
<td>Reduce need for energy. Use energy-efficient systems. Consider renewable and/or distributed energy resources</td>
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<tr>
<td><strong>Occupant Safety and Health</strong></td>
<td></td>
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<tr>
<td>Prevent slips, trips, and falls</td>
<td>Integrate daylighting into illumination scheme</td>
</tr>
<tr>
<td>Eliminate exposure to hazardous materials (e.g., volatile organic compounds (VOCs) and formaldehyde, lead, and asbestos in older buildings)</td>
<td>Use sustainable materials (e.g., no-VOC paint, formaldehyde-free finish panels, etc.). Use dedicated ventilation and/or exhaust systems in copy rooms, labs, loading docks, and mailrooms.</td>
</tr>
<tr>
<td>Provide good indoor air quality (IAQ) and adequate ventilation</td>
<td>Use daylighting. Consider integrated natural and mechanical ventilation systems. Use integrated building automation and control systems</td>
</tr>
</tbody>
</table>
3. Challenges of tall building design
Tall building can never be viewed in isolation. Their contribution to the growth of the city, their impact on the cityscape, their relationship with neighbouring buildings and their effects upon the people who use them are the ultimate tests. Future tall buildings which are sustainable, safe and secure will rebuild the confidence of owners, developers and public for its continual use in the urban environment.

For designing the new generation of tall buildings designers must strive for the highest quality and appropriateness for achieving both sustainability and safe-security objectives. A successful balance between economic, social and environmental effects can be achieved by an overall approach to building design – using the whole building approach. The understanding of the whole building approach is vital as it takes into consideration the interaction of the whole building structure and systems, and its context. In the past, research into isolated building components did not take into account how individual systems affect other systems.

Whole buildings design not only examine at how materials, systems and products of a building connect and overlap but also look at how the building and its systems can be integrated with supporting systems on its site and in its community. Incorporating this perspective into the designing, planning, and building stages can have significant effects on the outcome. For example, efficiency improvements that might be hard to justify on their own accord are seen in a different light when they result in a smaller heating and cooling system for the building. Synergies such as these are common in building designs, but are often overlooked.

Such consideration of potential synergies will foster the use of advanced building technologies that incorporate solar and other forms of renewable energy; and an integrated approach both to new-building construction and old-building renovations. Hence, the fundamental challenge of whole building design is to understand that all building systems are interdependent.

Designing for a secure/safe and sustainable facilities for buildings must be planned from the conception stage. The level of security/safety and sustainability incorporated in a facility varies greatly from project to project. Tall and iconic buildings have greater security risks will have to be given a comprehensive analysis on the various threat, vulnerability and risk assessment before security requirements can be identified and the appropriate reasonable design responses are integrated into the building design. Technical buildings benefit from whole building design where the integration of building systems contribute to the overall performance of the building during operations and emergencies.

In the light of the World Trade Centre tragedy, there is increasing emphasis for a holistic approach to design taking into consideration all aspects of safety including structural, egress and fire safety to enhance building performance in emergencies. The interaction of professions in design are crucial whereby the structural, fire protection, mechanical, architectural, blast, explosion, earthquake and wind engineering communities need to work together to develop guidance for vulnerability assessment, retrofit and to mitigate the probability of progressive collapse of tall buildings under hazard scenarios. (FEMA, 2002)

One of the challenges of designing a sustainable and safe/secure building will require the ability to think on trade-offs and synergies and creative solutions to achieve effectiveness in designs. Daylighting, natural shading, energy efficient, photovoltaic facades, wind power systems and sky gardens within tall buildings add up to a significant shift towards a more sustainable design of tall buildings. For a given budgetary constraint, balancing any these sustainable features with safety/security needs will be a real challenge to designers.

Tall buildings should be designed to be more permeable to people and more responsive to environmental conditions to embrace sustainable development. In the past decade, office buildings have transformed as companies realise that the interior layout has a greater influence on productivity. Besides designing for comfort, new tall buildings are designed for transformation of space to embrace openness and transparency to assist daily encounters and aim at encouraging new interactive ways of working. Whilst maintaining the sustainability objectives, designers should also give considerations to features which ensures the safety and well-being of the occupants.

Most of the tall building stock existed even before the sustainable building agenda arise and therefore tall buildings will present some of the best opportunities for implementing sustainable construction practices, particularly to improve energy efficiency. In this respect designers will have a choice to consider and balance the benefits of converting existing buildings (rather than demolishing and rebuilding them) in terms of reduced materials use and waste against the opportunities for designing a new building with low energy requirements, and using renewable energy.

Currently, best practices on sustainable building construction which view building construction in a holistic way is lacking. Such is needed to provide designers with examples effective design which presents the whole-life picture in a cradle-to-grave assessment. The support from a new generation of designers equipped with a multi-disciplinary knowledge on building systems will compliment to these efforts in achieving designs which are attractive, cost effective, energy efficient and flexible in meeting the needs of the occupants.
4. Implications on Design Education

4.1 Sustainability
The success of sustainability in design and in the built environment relies on how institutions of higher learning respond to the ideas generated as a result of widespread interest in sustainable development. If sustainability is to become an essential aspect of society and economical development then it has to become an essential part of education.

A complete integration of sustainable development across the curriculum, i.e. in all modules and parts of relevant subjects and activities through all phases is needed in encouraging sustainable design in buildings. The fundamental idea is that when sustainability is to become essential for all activities within society and all sectors of economy, it cannot remain as an isolated field of expertise but must form mindset for everyone (Venselaar et al, 2002).

Each course, project and other activity in the normal curriculum takes care of the issues relevant for sustainability connected with its own subject such as materials use, energy, design approaches, economics, etc.

Students must be trained to handle systems approach for finding sustainable solutions and implementation options for the short and for the long term. It requires multi-disciplinary and lateral thinking. The attitude and the competencies to do that are essential for a real sustainable development oriented engineer/designer.

4.2 Whole building education
The construction industry is fragmented where designers, engineers, and contractors perform their respective tasks without regard to the project whole. Similarly, most existing construction programs use the modular approach to education that provides well-conceived individual classes however fail to provide students with a complete understanding of how building systems are integrated.

The development of a whole building approach to design and construction education that will allow students to understand not only the parts of a building, but also whole building operations are vital. New curricula and techniques are needed for whole building education emphasising on how buildings are developed and designed, and how interdisciplinary teams can be used to maximize energy efficiency, reduce resource waste, and improve the environmental quality of the buildings being constructed.

4.3 Curricula
An implementation of the whole building design approach can be introduced into design classes. Innovative building materials and specifications can be incorporated into construction materials classes. The whole building education will provide holistic, integrative experiences for undergraduate students. This will respond to the increasing demands from the building industry for a more integrated approach to education as a means of securing closer and more effective collaboration among building design professionals (Jones, 1998).

Based on the whole building system, energy efficiency and indoor air quality can be used to guide the curricula of engineering classes. By using software tools like DOE 2 students can understand how equipment decisions affect energy performance. Whole building thinking can also be easily integrated into design build curricula.

Design through modeling and predictive simulation should be an important part of the design curriculum program to assist in the understanding of integrated design.

4.4 Collaborative learning
Since building systems are inter-related and that many design solutions may lead to other design problems therefore the design concept advocates to the use of inter-disciplinary teams that focus on systems approach to building design and construction. In order to create a successful building that performs well, an interactive approach to the design process is required. It is necessary for the people responsible for the building design to interact closely throughout the design process and that everyone involved in the use, operation, construction and design of the facility must fully understand the issues and concerns of all the other parties.

Many improvements are necessary in the orchestration of the complicated process, in order to take benefit of available technologies and products. A collaborative learning approach introduced to students will expose them to real problems of building design. The recommendations for cross-disciplines seemed the best solutions for whole building design and therefore should be addressed accordingly by educational institutions.

4.5 Performance-based design
To date, many countries have already undertaken the development of performance-based specifications. Later, these specifications will likely be preceded by the development of performance-based building codes. Different stakeholders will benefit from performance based specifications. These specifications will improve the reliability of buildings and build in guarantees to reduce their environmental impact. Owners and manufacturers will benefit from the increasing opportunities to apply new materials and new technologies (Augenbroe et al, 1998).

The wide spread adoption and implementation of the
Leadership in Energy and Environmental Design (LEED) rating system, developed by the United States Green Building Council (USGBC) is closely linked to performance based standards. LEED rates the environmental aspects of a building and the behavior of its occupants to arrive at a final score that results in a platinum (highest level), gold, silver, or bronze plaque being awarded.

A wide range of issues are evaluated to include energy and water use, indoor health, recycling for occupants, access to mass transit, materials impacts, landscaping, construction waste management, building sites and maintenance.

The LEED benchmarking system for sustainable design is one way of tracking and quantifying the potential sustainable savings and is rapidly gaining recognition by the design community as a viable mechanism.

Introducing performance based design in the design curriculum and use of evaluation methods applied by industries to assess building performance will provide qualified professionals relevant to industrial needs.

4.6 Industry education and Professional development
Industry education is needed to increase the awareness of stakeholders and professionals on current design practices for tall building and to facilitate mainstreaming of sustainable building design in construction. Current barriers to implementations of sustainable/high performance tall buildings include the lack of knowledge about the economic and environmental benefits of such buildings, as well as a dearth of familiarity with sustainable building concepts and practices.

Currently, the US Green Building Council and similar organisations from various parts of the world including the International Initiatives for Sustainable Built Environment (iiSBE), the International Council on Research Innovation in Building Construction (CIB), and The United Nations Environmental Programme (UNEP) are promoting the sustainable building agenda at both regional and global levels mostly aimed at building capacity and developing action plans for the implementation of sustainable building construction. These include regional conferences in Europe, South America, Africa, China and South East Asia to be held in 2004 followed by the World Conference on Sustainable Building 2005 in Japan. These programmes are complimented by best practices award to encourage participation from stakeholders.

The United States Green Building Council trains designers, builders, owners, and operators of public and private facilities to implement green strategies. The manual offers step-by-step guidelines for energy-and resource-efficient building during pre-design, design, construction, operations, and management. It also includes chapters on sustainable building economics and future issues and trends. The manual provides practical guidance for design professionals, contractors, product manufacturers, building owners and tenants, facility managers, utilities and management.

4.7 University-industry research
An important implication for construction educators is the substantial need for applied research in sustainable tall buildings to support the industry needs and improve performance in tall buildings.

Designers in industry would benefit if research produced tools, methods and theories that add structure to complex design processes and reduced design iterations. It is increasingly necessary to apply structured, methodical approaches to design projects. There needs to be an increased emphasis on robust design methods and validation. Better mechanisms for team decision-making are needed, including decision-making under risk and uncertainty [NSF (1995), Steemers (2003)].

5. Conclusions
For designing the new generation of tall buildings designers must strive for the highest quality and appropriateness to achieve both sustainability and safe-security objectives. The design challenges to enhance the performance of tall buildings are great especially for rebuilding the confidence of owners, developers and occupants. Supports are required from all concerns to put these design approach into mainstream.

Sustainability along with whole building thinking should be considered across the construction and design education curriculum to lead future tall building designers into a rapidly changing design and construction industry. The reform in design education to incorporate collaborative learning and lateral thinking is essential to respond to the increasing demands from the building industry for a more integrated approach to education and, a means of securing closer and more effective collaboration among building design professionals.

Industrial education is equally important to increase awareness in stakeholders and professionals on current design practices to encourage implementations of tall buildings designs which are economical, social and environmental friendly.

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