A FRAMEWORK TOWARDS ENHANCED SUSTAINABLE SYSTEMS INTEGRATION INTO TALL BUILDINGS DESIGN

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Keywords

integrated systems; sustainable architecture; passive and active renewable energy; natural lighting; passive cooling; iconicity.

Abstract

Sustainable tall buildings are increasingly under rapid development and scrutiny worldwide. This will pave the way to a new generation of buildings designed in a unique form of Architectural systems integration. That is to say, finding new ways to integrate the systems, finding new common grounds and perhaps more comprehensive optimizations. The significance of integrating sustainable systems within tall buildings is the corner stone in delivering sustainable tall buildings globally. The paper looks into ways and means to better integrate passive and active renewable energy technologies and systems, green and sustainability measures into tall building’s design. Other issues such as architectural Iconography, and heritage and cultural influences on tall building’s design are also mentioned. The objective is to develop a framework for sustainable systems integration in buildings, proposing areas of further integrations customizable to any particular site context. The focus is on key sustainability strategies that drive design solutions to obtain maximum natural lighting, ventilation, heating and cooling, solar electricity/heat generation, possibility of wind energy generation and ground sourced amenities. Some design cases are presented exhibiting these strategies and design options, which clearly demonstrates the potential of tall buildings in creating a promising dense and sustainable future for cities around the globe.
INTRODUCTION

The notion of sustainable design pertains to nature’s spontaneous change and adaptation. This comes in a variety of forms such as morphology, morphogenesis, growth, complexity science, turbulence and form. They all have self-generated processes in nature to develop to some stage of processes and cycles. D’Arcy Wentworth Thompson (1917) in his book ‘Landmark on growth and form’ mentioned this tendency of nature to self-changing forms. These processes and complexities are sympathetic to architecture’s quest for meaningful expression. Architectural design thinking centres about creating a holistic solution that is composed of many components resolved by its final intent to be visually, physically and functionally acting together to deliver the amenities required from buildings in question. This classification of a building’s components working together is a guide to distinguish between different integration ideas. If we consider a multi-layer façade of triple skin for instance (i.e., a sandwich layer of photovoltaic (PV) louvers between two layers of glazing) regulating heat transfer, natural light, passive ventilation, heat recovery from photovoltaics, shading, barrier from elements and appearance. This simple example transcends the mere visual, physical and performance integration solutions mentioned above, to a more environmentally conscious solution reducing the environmental impact of energy generation by onsite generation, no CO₂ emissions, natural ventilation, heat recovery and energy generation with added comfort, quality natural lighting and a potentially pleasing façade. Furthermore, when heat is recovered from PV by preheating ventilation air we maintain PV efficiency while saving the energy to heat ventilation air. When shading interiors by PV modules, we reduce direct heat gain, reduce and maintain natural lighting levels, reduce glare and generate electricity. Therefore, the final design product no matter how large or small it may be comes with quality answers at various levels, with a flare helping to promote given contextual settings at micro and macro size.

The significance of the present work lies in opening new horizons and pathways for sustainable systems integration within tall buildings that render them sustainable and in conciliation with environmental settings. It is given that tall buildings by nature consume large amounts of energy and resources in their construction as well as throughout their operational life. Providing a means to correct this or turn it into energy generating, resource enhancing, environmental sustaining and cultural preserving contributors would go a long way. This would result when mindfully integrating ‘sustainable technologies’ into designing tall buildings with enhanced integrations encamping all these matters in mind. We can point out some of the characteristics of these technologies or systems rendering them integration worthy in the following points.

ACTIVE RENEWABLE ENERGY SYSTEMS

Active renewable energy systems utilize natural elements within a given site as sources for energy in such a way that ensures natural regeneration maintained. These systems vary in their design and requirement to tap on the resources. They generally require a conducive design optimized for their operation. Examples are sun, wind, ground and water operated devices. Each system obviously can work independent from any building. However, when integrated into buildings’ fabric, buildings attain sustainability. Therefore, careful integration strategies and optimizations need to be in place to ensure success. We can differentiate between two major categories of systems according to their integration:
Externally integrated: that have to do with visual integration predominantly, from the architectural point of view, examples being solar powered systems, like solar thermal, natural lighting, photovoltaic modules etc. They need to be externally mounted/integrated on building facades to be able to capture the resources. There is great potential in providing a higher level of integration for these technologies as they can combine all types of systems integration - visual, physical and performance - quite easily when carefully studied.

Internally integrated: that have to do with physical integration. Examples can be any cycles based systems that has no direct contact with the outside elements, such as fuel cells. Here either physical or performance integration are more common. Perhaps both types of integrations are experienced here when suitable requirements persist.

Much research work has been undertaken that can be linked to the topic of renewable energy integration into buildings such as Zhang et al. (2015) review on a solar thermal façade system and its components in different publication and its result of integration into the visual, performance and façade systems.

Elbakheit (2014) Introduced a methodology to optimize the performance of wind resources harnessing around buildings by using aero foil shapes around building fabric (roofs and/or facades). Werner et al. (2013) focused on the interaction of smart design, using renewable energy resources and low life cycle costs to create and use buildings not just in a green but also in a blue way. This means not just creating buildings with zero waste, but very naturally regenerated building amenities. These systems (i.e., Renewable energy systems) can be the backbone for sustainable Tall building design Ideas such as, Sun tower, Solar power tower, Minimum surface (wing) tower, Wind tower, Light transmitting tower and so on. A Tall building can rely immensely on a system or two due to its potential in any specific site qualities, while incorporating other systems to complete its functions.

PASSIVE RENEWABLE ENERGY SYSTEMS

These are systems that depends on natural materials properties, the way they are assembled, and naturally occurring phenomena or processes such as heat transfer, materials' properties etc., depending on the actual building construction, its design, detailing, specification and assemblies. We provide natural lighting (i.e., a renewable source) through windows (i.e., a passive system) that are properly oriented, insulated, shaded and appropriately specified.

Passive systems generally work best when coupled with renewable active system, such as the previous examples in the introduction. Another example could be, in a direct-gain passive solar heating system, the floor of the sunlit space is sharing the thermal work of the envelope and the mechanical heating system by providing thermal storage in its massive heat capacity, which limits indoor temperature swings from sunlit day to cold clear sky night. The envelope, structure, interior, and services integrated by the shared thermal mandate of maintaining comfortable temperatures. There is a number of research work that has been done with these systems in mind such as Agrawal (1992) who mentioned some broad strategies to achieve passive cooling and heating within buildings by employing basic physics of building materials.
Beck, Korner, Scheller, Hauck & Fricke (1994) discussed the use of transparent insulations and their ability to control both light transmittance (from 85%-10%) and heat gain/loss (down to 5W/m²) in ways that achieve better integration of light/heat envelope performance. Additionally they discussed many materials that have distinctive solar properties developed to regulate solar power in myriad of ways. This is a physical, visual and performance integration with just a single material used in facades. On the other hand, Granqvist (2003) tested materials used to regulate as well as store solar power as an array of energy scavenging photodiodes based on a passive-pixel architecture for CMOS imagers.

Integrated vertical plate capacitors enable dense energy storage without limiting optical efficiency by Guilar, Kleeburg, Chen, Yankelevich, and Amirtharajah (2009) where measurements indicate that 225 μW/mm² output power may be generated by white light with an intensity of 20 k LUX, which indicate an integration of passive and active systems in one system.

Stack effect as a passive ventilation strategy investigated by Lomas (2007) showed a much more cost effective option than some mechanically operated and more energy consuming systems. Passive solar considerations in Tall buildings studied by Lotfabadi (2015). In this study, an example of Bishopsgate, London tower passive and active solar systems savings were quantified. Vertical greenery as a passive system was also reviewed by Perez, Coma, Martorell, & Cabeza (2014). Kheir Al-Kodmany (2016) presented a number of tall buildings with innovative passive and active renewable technologies helping to achieve environmentally friendliness of dense cities worldwide. Based on these technologies designers can produce tall building ideas such as Vertical farming tower, Biologically growing tower, Water Harvesting tower, Flower Tower, Tree tower, Fibonacci tower, Recursive structure, Exoskeletal tower and so on.

ENERGY EFFICIENT SYSTEMS

Energy efficient systems are either mechanical or electrical apparatus, which transfer some form of power into another (i.e., electrical power into cooling or heating, heat into refrigeration, motion into electricity and so on) but at higher coefficient of performance (COF). An indicative example of these systems are heat pumps used in most refrigerators, air conditioning units and various refrigeration cycles. Heat pumps work on principles of heat transport from one medium to another such as air-to-air, air-to-water, and air-to-earth. In doing so, it can incorporate/integrate these natural resources (i.e., air, water, earth, etc.) of any site or location for more enhanced performance. Furthermore, this gives greater potential for designers to innovate combined systems customized to every design situation. One type of energy efficient systems is the adaptive automation of building components to cope with several real life design conditions, such as Adaptive facades, and deployable shading devices. Some of these systems may work on integrations between passive systems and normal systems to arrive at an energy efficient system, like the case of phase change materials to operate façade shutter, or photosensitive cells to control shading devices.

INTEGRATION FRAMEWORK UNDERLYING STRATEGIES

The architect’s role is not only understanding the interaction and relationships of building systems and their connectivity in order to provide for them in design, but to draw meaningful conclusions and workable processes ultimately manifested in the form of building
components. Building systems being site, structure, envelope, servicing and interiors, amenably integrated within buildings in infinite ways. Each of these major systems have sub-systems that interact with major systems and indeed with other sub-systems in a myriad of ways. We can list just a few indications for these possibilities in Table 1 below. Obviously different building design conditions and requirements would dictate appropriate solutions of integration type.

Table 1: Possible types of integrations between different building systems

<table>
<thead>
<tr>
<th>Site</th>
<th>Structure</th>
<th>Envelope</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior</td>
<td>Indoor/outdoor</td>
<td>Daylighting/natural ventilation</td>
<td>Exposed ducts/ Acoustics’ tiles/ Luminaires Return air</td>
</tr>
<tr>
<td></td>
<td>relationship</td>
<td></td>
<td></td>
</tr>
<tr>
<td>services</td>
<td>Cooling Ponds/ Earth cooling</td>
<td>Ducts routes/ interstitial mechanical plenum</td>
<td>Passive design/ Vented skin/ Solar roof/ Double skin</td>
</tr>
<tr>
<td>envelope</td>
<td>Earth Shelter</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Natural Habitat</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Noise barrier</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Storm water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>structure</td>
<td>Underground</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>terraces</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A further step would be realizing a framework for integrating the above studied systems (i.e., Renewable energy, passive systems and energy efficient systems) in a pragmatic and systematic manner to produce enhanced sustainable systems integration. Table 2 below depicts some scenarios of potential integration between these technologies and the known building systems. Obviously, these are hints or guidelines for attainable further integration that would yield better energy savings, usefulness of the design in delivering the required performance, physically, visually and performance wise. The degree of success and indeed complexity of the integration solution would lay on the special circumstances, Architect’s or/and Client's vision, and challenges involved.

Table 2: Anticipated types of integrations between building systems and sustainable systems.
(Source: Author).

<table>
<thead>
<tr>
<th>Site</th>
<th>envelope</th>
<th>structure</th>
<th>system</th>
<th>interior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renewable energy</td>
<td>Wind</td>
<td>Natural light</td>
<td>Photovoltaic</td>
<td>Wind turbine</td>
</tr>
<tr>
<td></td>
<td>Sun</td>
<td>Solar +wind Technologies ventilation</td>
<td>Solar thermal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ground</td>
<td>Performance +visual integration</td>
<td>Physical integration</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical integration</td>
<td>Artificial lighting</td>
<td></td>
</tr>
<tr>
<td>Energy efficient</td>
<td>Water ponds Earth</td>
<td>Performance +visual integration</td>
<td>A/C &amp; ventilation Heat recovery</td>
<td></td>
</tr>
<tr>
<td>Passive systems</td>
<td>Greeneries Orientation Sun heating</td>
<td>Natural lighting Ventilation cooling Insulation Shading devices</td>
<td>Physical integration + visual integration</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical integration</td>
<td>Buoyancy</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Natural lighting</td>
<td>Physical +performance integration</td>
<td></td>
</tr>
</tbody>
</table>
MAIN STRATEGIES

Perhaps the most effective and scientifically benign strategy for solar and indeed environmental building design as a whole is to orient buildings towards the North/South direction, where the largest elevations would be North and South, and East and West elevations at a minimum length. This would promote direct sunlight access in wintertime and less in summertime, and enhance the use of shadings and reflected light from the surroundings. Asfour (2007) presented a tall building (Amwaj Residential Tower, Kuwait) that gained acceptance and generated high demand and popularity from the public for adopting these principles. In addition, all active and passive solar-based technologies will have the maximum solar energy for its operation. Further optimization of orientation may be required; however, it would be specific to any given location such as a slight inclination towards the South East, for more winter solar access. East and West orientation will expose the facades for more light summer than in winter and therefore, more heat in summertime. Shading normal windows here also blocks vision, therefore, high levels windows are preferred here and if they are well shaded can provide an even distribution of light throughout a single day and ultimately throughout the year.

A further repercussion to proper building orientation is that all solar-based technologies would have optimum exposure for sun light at 70-100% of daylight hour's duration daytime, a fact that capitalizes on huge savings in operation and running costs when fully utilized. Another main strategy concerns Architectural expressions (Kheir. Al-kodmany, 2014) and their relationship with some of low energy design measures. Architectural form can be used as a means to fulfill energy conscious tall building design and energy efficiency (Elbakheit, 2012), cool air storage and double skin as a means for solar control in buildings (Nicoletti, 1998). Last but not least, vertical greenery systems can act as a passive tool for energy savings in buildings. Green walls and green facades have the highest potential in the cooling mode of buildings to reduce energy, however, careful attention should be paid on which plant species are more suitable to a certain climate, and substrate layers for vegetation especially in wall systems (Perez et al., 2014).

Supporting Tools

The careful study of different potential integrations of systems, whether renewable, energy efficient or passive, can be sufficiently realized by building performance simulations (BPS) tools. These tools vary in form, complexity, and outcome but all have a digital platform. Of course, most of the successful integrations would depend mostly on our deep convictions and understanding of the underlying principles and operational characteristics of systems. BPS tools will assist us in evaluations of systems integration, finding tradeoffs and reveal strength and weakness of perceived integrations. On the other hand, the advances of these tools may make it easier for designers to exhibit not only the 3-dimensional presentations but the anticipated environmental conditions and energy savings, or operational characteristics as well.

Examples of Proposed Integrated Sustainable Tall Buildings Design Solutions:

First Example: (Madinah Mixed-use Centre): This is a project comprising Landmark towers in a newly proposed ‘knowledge economic city’ in the holy zone of Madinah city at 5 Km from Prophet Mohamed (PBUH) Holy mosque, the second holy land for Muslims after Mecca. The towers are to accommodate a mixed-use development to be a focal point in the
city. This poses a great challenge to design a building that is culturally, socially, environmentally and economically responsive to its context with facilities for rental offices, hotels, mall, entertainment, cultural and social amenities. The answer was in the form of three inter-connected towers with links at focal points within the stretch of building height (Figures 1-4). Two of the towers accommodate hotels and the third being the tallest for offices (Figure 2). A number of links cross between the three towers at focal points (i.e., above service floors) along the height of the development (Figures 1-4). The design responds to various issues as follows:

**Climate:**
Medina is at latitude 27.9 North with a climate similar to Mediterranean, (i.e., cold damp in winter, hot dry summer). However, generally there are nice temperatures and conditions most of the year with moderate temperatures in Fall and Spring. Therefore, it is only the extreme heat and cold is the issue here, and this is solved as follows:

**Orientation:**
The three building blocks are rectangular in plan oriented to face North and South along their length with widths facing East and West. This helps to reduce heat gain and glare in summer time, whilst increasing natural lighting from the North, and allowing warm winter sun from the South. The buildings gather to form a triangle shape, each occupying a tip of an isosceles triangle (Figures 1-4). Triangles are common in most traditional folklore of the KSA. This orientation made it possible for natural wind passage from West to East (i.e., land-sea breeze, its less than 200 km from Red Sea) and vice versa to filtrate around and in-between towers. Thus, maximizing natural ventilation and reducing wind load impact on facades, since the blocks faces wind with the shortest of their facades. In addition, optimized wind turbine shrouds are located accordingly on tops of each tower.

**Social Connections:**
Further enhancement to the form is made with reference to clusters of traditional Medina rectangular houses, compactly gathered with linking passages and courtyards. Links are reproduced horizontally and vertically between the towers so they connect with three links located every 7-10 floors. These links serve as spaces for cultural, social and recreational activities overlooking the Medina Skyline (Figure 2).

**Environmentally:**
A number of technical solutions were carefully selected and fine-tuned with the 3-D form of the building to deliver sufficient daylight, with total privacy and little glare by sun breakers and Mashrabia (traditional wooden patterns to control natural light inwards). Energy generation comes from solar cells covering the podium atrium, which houses the Mall. The pinnacle of each of the three towers accommodate wind turbines with optimum wind orientation and shape of spoilers. Green roofs, atrium and sufficient insulation are also incorporated.

**Cultural and Heritage Sensitivity:**
Some vocabulary of cultural and heritage buildings in the area are carefully incorporated and introduced but in a new architectural disposition. These include arcades, clustered building forms, covered links and Mashrabia just to mention a few. Full access is provided between the towers vertically and horizontally, through links to cultural facilities such as meeting rooms, auditoriums, ceremonial halls, restaurants, mall and retail. These are married to the environmental design principles with full access to natural lighting, wind, and views to produce a form worthy of exhibiting an iconic image (Figures 1 and 2).
Figure 1: Basement, ground levels and a 3D view of the tower (Source: Author’s Tall buildings studio Year 2015).

Figure 2: 3D concept and functional distribution (Source: Author’s Tall buildings studio Year 2015).
Figure 3: 3D configurations and front and Back elevations (Source: Author’s Tall buildings studio Year 2015).

Figure 4: Environmental solutions integration within the towers (Source: Author’s Tall buildings studio Year 2015).
Second Example: (Riyadh Mixed use Centre)

Another example of applications to the underlying strategies integrating sustainable technologies in tall buildings is a mixed-use tower for hotel, retail, office, recreational and hospitality (Figures 5-9). The tower is proposed for a site in Riyadh downtown. It was designed facing North for maximum daylight and views across the city. Full cover of traditional patterns is applied to these (North and South) facades. Patterns are made denser towards the sides and less dense in the middle of the facades for more control on sunlight lower angles (early morning and late evening suns; Figures 8-9). This integrates daylighting from the site with the envelope system of the tall building that resonates in every floor of the tower. The tower meets the ground in a large podium that rises up to four-story height housing retail, some recreational activities and hospitality. The podium is in the shape of three large arched shells of space frame, juxtapositioned on the North and South sides of the site. High-level clearstory windows are located all the way along the junction between these staggering arches (Figures 5, 7 and 8). Offices are accommodated from 10-30 floors forming a contained village of self-sufficient services, while the hotel is placed from the 31-60 floors. The hotel has a huge atrium in the middle that works as a living lung to the building that admits natural light and circulates ventilation by stack effect. The tower is topped with a steel frame with a swimming pool on top of the atrium (Figures 5, 7 and 8).

Figure 5: Site plan (Source: Author’s Tall buildings studio Year 2015).
Figure 6: Podium and Tower ground floor (Source: Author’s Tall buildings studio Year 2015).

Figure 7: Sections (Source: Author’s Tall buildings studio Year 2015).
Energy Savings from System Integration

Lighting

The above buildings are examples of those which have full reliance on natural lighting 100% of the working hours: the working hours are from 8AM-3PM, with the shortest daytime hours falling on December 21st from 6AM-5:30PM throughout the majority of KSA. Further integration of natural renewable lighting with energy efficient artificial lighting produces
quality comfortable lit interiors. Obviously, full natural lighting reliance would eliminate lighting costs in daytime while merging natural and artificial lighting can save over 50% from running costs in deeper plans of 12m from normal windows. Energy efficient lighting can save over 60-80% of running costs.

**Cooling**

- Total removal of direct solar gain that would reduce (1000-2000 W/m²) of the total cooling loads by shading devices, Mashrabia, Atriums and proper building orientation. This would amount to a significant reduction in the energy required to cool buildings. Apart from natural lighting provision, Atriums can assist natural ventilation and/or pre-heat natural ventilation according to design configurations.
- Provision of natural ventilation from prevailing Sea-Land breeze.
- Green roofs irrigated by recycled grey water and harvested rainwater. Not only does this reduces direct sun gain (by the amount of 1000-2000w/ m²), but it also acts as a thermal insulation (i.e., saving 13% of annual energy consumption, ASHRAE Baseline), and added passive evaporation cooling from vegetation. Thus, it is a visual, physical and performance integration into a single building element (the roof).

**On Site Solar and Wind Energy Generation**

The employed design strategies depicted in the paper paves the way to introduce wind and solar renewable energy technologies from onset, with the possibility to add further solar and wind technologies later in the building’s life. Thus providing for a continuous and sustainable source of energy.

**CONCLUSION**

The significance of Active and passive renewable energy systems as well as energy efficient systems in delivering sustainable Tall buildings cannot be understated. Their successful integration within building systems comes in infinite ways. When so doing, more benefits are attained at fewer costs and add benefits financially, environmentally and contextually.

Arriving at a culturally and contextually responsive architecture is subject to the architect’s instinct of extracting meaningful representations from a given location’s cultural disposition expressed visually, in facades, forms, colours, textures and so on. However arriving at an environmental and sustainable building can be through an extensive pragmatic framework of relations and interaction between different systems and their environmental settings, both natural and manmade, as examined in the present work.

The present work proposes a framework for a more proactive integration of sustainable technologies into tall buildings customized to any specific context, highlighting the qualities, pre-requisites and relationships of Renewable technologies, energy efficient technologies and passive architectural systems that can inform architectural design to arrive at enhanced architecturally sustainable solutions. In addition, the work points out successful architectural strategies linking active and passive systems for more enhanced integrations.

As an academic taxonomy, there are three types of systems integrations, visual, physical and performance. However, with architectural ingenuity a single system can provide all amenities of visual representations, physical proportions and perform vital functions such as the examples in this work. Thus, it is stipulated as enhanced architectural integration.
The benefits of such enhanced integrations are immense. Financially instead of buying many systems and systems components, a single integrated system is devised that encamps different functions together at a lower cost. In addition, in tall buildings each integrated system would provide an incremental saving that when repeated in each level multiplied by the size of a skyscraper, generates huge savings. Environmentally, designing with the environment for the environment by the environment. Culturally, allowing expressions of cultural dimension clearly pronounced and articulated.

Performance, conditions that are more comfortable secured with better services and lower costs. Building performance simulation (BPS) can provide a means to examine, quantify and optimize different integration strategies in buildings. With further development of BPS more prospects of building systems integration may be evident. Tall buildings have great potential for successful systems integrations, energy saving, energy generation, passive systems, quality environmental control in a concentration unrivaled by any building type thus, forming a successful typology for sustainable developments in urban settings worldwide.

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