Title:	**Towards Resource-Generative Skyscrapers**
Authors:	Mohamed Imam, University of Calgary Branko Kolarevic, University of Calgary
Subjects:	Architectural/Design IT/Computer Science/Software Social Issues Sustainability/Green/Energy Urban Design
Keywords:	CFD Density Energy Efficiency Height Performance Based Design Renewable Energy Urban Planning
Publication Date:	2018
Original Publication:	International Journal of High-Rise Buildings Volume 7 Number 2
Paper Type:	1. Book chapter/Part chapter 2. **Journal paper** 3. Conference proceeding 4. Unpublished conference paper 5. Magazine article 6. Unpublished

International Journal of High-Rise Buildings
June 2018, Vol 7, No 2, 161-170
https://doi.org/10.21022/IJHRB.2018.7.2.161

International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

Towards Resource-Generative Skyscrapers

Mohamed Imam[1†] and Branko Kolarevic[2]

[1]*University of Calgary, 603, 180 Switchmen Street, Vancouver, Canada. V6A 0C7*
[2]*University of Calgary, 2500 University Dr NW, Calgary, AB T2N 1N4, Canada*

Abstract

Rapid urbanization, resource depletion, and limited land are further increasing the need for skyscrapers in city centers; therefore, it is imperative to enhance tall building performance efficiency and energy-generative capability. Potential performance improvements can be explored using parametric multi-objective optimization, aided by evaluation tools, such as computational fluid dynamics and energy analysis software, to visualize and explore skyscrapers' multi-resource, multi-system generative potential. An optimization-centered, software-based design platform can potentially enable the simultaneous exploration of multiple strategies for the decreased consumption and large-scale production of multiple resources. Resource Generative Skyscrapers (RGS) are proposed as a possible solution to further explore and optimize the generative potentials of skyscrapers. RGS can be optimized with waste-energy-harvesting capabilities by capitalizing on passive features of integrated renewable systems. This paper describes various resource-generation technologies suitable for a synergetic integration within the RGS typology, and the software tools that can facilitate exploration of their optimal use.

Keywords: Energy efficiency, Multi-objective optimization, Performance-based Design, Renewable energy, Resource generation

1. Introduction

1.1. The Necessity of Tall Buildings

High-rise buildings emerged in the mid-1960s as a principal architectural typology to address the growing need for increased density in city centers (Ko et al., 2008). This architectural solution aimed to provide maximum usable space from the least possible amount of land to accommodate the ever-increasing urban population. The population living in urban areas during the 1960s was close to one billion (about 30 percent of the planet's three billion people), whereas current projections for 2050 predict an urban population of about six billion – about two-thirds of the over nine billion people that will be living on the planet in the future (UN, 2014). The population surge and expanding urbanization have played a key role in the continued boom of skyscraper construction during the past decade. Skyscrapers' urban expansion, in both numbers and heights, is projected to reach even higher – at the upper extreme, approximately 1,000 meters, in the case of the under-construction Burj Al-Mamlakah (Jeddah Tower) in Jeddah, Saudi Arabia (Weismantle & Stochetti, 2013).

1.2. The Problem

Unfortunately, the casualty of rapid urban expansion is an inevitable and oftentimes dramatic depletion of the city's resources. As cities grow to accommodate the increasing population, the expansion overtakes adjacent areas used for resource production, such as agricultural land. Moreover, strained farmland yields are regularly subjected to further losses due to transportation, with agricultural losses reaching 30 percent in Europe and North America (Gustavsson & Cederberg, 2011). Similarly, substantial losses occur in energy transmission. A typical power plant source is only 30 to 35 percent efficient by the time energy reaches the building (Frechette & Gilchrist, 2008). Consequently, it seems imperative to re-examine the modern city's resource generation and distribution systems. Greater emphasis on local production within a city center is vital to decrease excessive transportation losses and increase the potential of open areas and parks.

1.3. Pros and Cons

Critics opposing the tall building typology remain convinced of its ineffectiveness (Roaf et al., 2009), despite its apparent necessity – particularly in a densified clustered setting – to limit land use and accommodate increased population and growing urbanization. Criticisms against this "urban evil" highlight concerns, such as increased costs from requiring special construction equipment and expertise, in addition to the subsequent operational and maintenance costs (Ali & Al-Kodmany, 2012), straining on infrastructure and transportation systems, overshadowing of surroundings, consumption of large amounts of energy (Al-Kodmany, 2012), and decreased usable floor efficiency (60 to 70 percent) relative to low- or mid-rise

[†]Corresponding author: Mohamed Imam
Tel: +7782310610; Fax: +
E-mail: mohamedimam@ucalgary.ca

buildings (Watts & Langdon, 2010); however, critics emphasize these drawbacks without offering a viable alternative to address overpopulation and escalating urban densities. Hence, skyscraper construction continues to thrive, with more skyscrapers completed in the previous decade than any previous period in history (Al-Kodmany, 2012). A dramatic change in use has recently occurred in many newly constructed skyscrapers, with an increase in hotel, residential, and mixed-use functions by six percent, 16 percent, and 28 percent, respectively. On the other hand, the office function in skyscrapers – which used to dominate skyscraper developments – has decreased by 50 percent (Wood, 2015).

The driving forces for this skyscraper boom are well beyond merely offering a solution for high urban densities. Supporters of skyscrapers cite many advantages, such as urban regeneration (Nordenson & Riley, 2003), lesser land consumption (Wood, 2013), preservation of open spaces (Al-Kodmany & Ali, 2013), and financial practicality due to extreme land prices in city centers (Al-Kodmany, 2012). The most important advantage, however, is the ability to create more compact urban living in city centers. Compact city developments have proven successful in cities such as Hong Kong (Newman, 1996) by decreasing driving distances and consequently reducing transportation carbon emissions. By applying this concept in North America, driving distances can be decreased by up to 40 percent (Ewing et al., 2008).

1.4. Untapped Potential

Despite the criticism of high resource consumption, tall buildings remain one of the most feasible design solutions in densely populated conurbations (Cichy, 2012), as a single supertall building in a clustered high-rise city consumes approximately seven percent of the land relative to the dense courtyard typology, and one percent of land relative to a typical urban house, even when housing the same number of people (Drew et al., 2015). The immense advantages that skyscrapers possess over other architectural typologies can be further enhanced by improving their performance efficiency and generative capabilities. Potential performance improvements can be explored using multi-objective optimization (MOO) aided by parametric design tools (Ashour & Kolarevic, 2015). Evaluation tools such as computational fluid dynamics (CFD) (Malkawi et al., 2004) and EnergyPlus® (Ellis & Torcellini, 2005) can be used with MOO to explore skyscrapers' generative potential. Using these software tools, a designer can visualize and explore multi-resource, multi-system generation optimization. An optimization-centered, software-based design platform can potentially enable the simultaneous exploration of multiple strategies for decreased consumption and the large-scale production of multiple resources, such as energy, food, water, and land. Furthermore, this platform can aid in exploring the feasibility of harnessing sky-sourced energy with increased building heights, due to variations in temperature lapse rates, airflow, stack-effect patterns, air moisture, and density (Leung & Weismantle, 2008). Obviously, the design strategies based on resource generation require further research to improve the potential of future high-rise developments in high-density city centers (Oldfield et al., 2014).

1.5. Resource-Generating Skyscrapers

The city centers' rapid urbanization, resource depletion, and limited land will only increase the need for skyscrapers, which will continue to define the fabric of the modern city. Resource-Generative Skyscrapers (RGS) are a possible solution to further explore and optimize the generative potentials of skyscrapers, and thus address the significant issue of the city centers' resource depletion. RGS can be optimized for waste energy harvesting capabilities by harnessing sky-sourced energy and capitalizing on passive features of integrated, active renewable systems. Furthermore, RGS can be strategically positioned in densely populated city centers. Through the concept of compact cities, and by co-locating resources, production and consumption, RGS can have an effective radius of influence. This radius can contain locally harvested basic resources (energy, food, water, and land) which can relieve the need for transporting resources from the city's outlying areas. Additionally, by expanding the tall building influence domain in the RGS typology, the supporting compact infrastructure and transportation systems can be developed promptly by shifting the required infrastructure expansion from the public to the private (RGS) domain.

2. Energy Efficiency in Skyscrapers

Skyscrapers have significant potential to be further optimized for energy efficiency and other environmental considerations via thermodynamics and energy flow analysis, which can guide the typological evolution of skyscrapers (Li et al., 2015). The R^2AG formula for high-performance skyscrapers – Reduction, Reclamation, Absorption, and Generation – is a methodological approach to sustainability used in most skyscrapers for its ability to reduce the building's resource consumption, and then establish a connection to the surrounding natural energy streams, prior to adding any costly on-site generation capabilities (Frechette & Gilchrist, 2008).

2.1. Reduction

The initial approach for higher efficiency is to reduce the building's consumption. The primary step is capitalizing on the natural assets of daylight, solar radiation, and natural ventilation extracted via efficient external single- or double-skin envelopes, solar chimneys, wind catchers, etc. (Watts & Langdon, 2010). Subsequently, central mechanical systems – whether water-based (chilled beams), or variable-flow air systems (VAV) – can be developed accordingly (Parker & Wood, 2013). Water supply and

Figure 1. Commerzbank Tower. (Source: Mylius, 2009).

use reduction can be achieved via gravity-induced water supply from water tanks integrated at intermittent levels, coupled with the use of low-flow sanitary fittings and water reclamation. For example, the Commerzbank Tower (1997; see Fig. 1) located in Frankfurt, Germany, and designed by Foster+Partners, deployed passive strategies that relied on the tower's geometry; strategies included natural illumination and ventilation through a central atrium spanning the full tower height, optimized façade design to allow natural ventilation via operable windows, and a water-based chilled ceiling cooling system (Oldfield et al., 2009).

2.2. Reclamation

The principle of reclamation is to recapture and reuse the injected energy in the building, refraining from introducing newly harvested energy or water into the envelope (Parker & Wood, 2013). Examples of reclamation strategies include air-to-air heat recovery, which can be used to reduce the incoming external air's heating/cooling loads by transferring the exiting high-energy-content air stream to the incoming one. Similarly, the use of a heat exchanger before greywater discharge can extract waste heat for domestic hot water usage. Additionally, reclaimed greywater and rainwater can be treated and used for non-potable water use, such as toilet flushing, cooling tower water make-up, and irrigation of vertical vegetation (Simmonds, 2015). Reclamation can also be applied to cooling coils' condensate water deposit from the cooled/dehumidified external air introduced into skyscrapers (Parker & Wood, 2013). The Pearl River Tower (2011) in Guangzhou, China, which was designed by SOM, successfully employed reclamation strategies such as re-circulated air for the pre-conditioning of outside fresh air prior to distribution (Frechette & Gilchrist, 2008).

2.3. Absorption

Skyscrapers' inherent footprint and height expose them to abundant energy streams of ground-, solar- and wind-sourced energy. Absorption technologies include geothermal energy, where tapped ground temperature lags air temperature by a range function of depth. By using a heat pump, concentrated heat energy can be extracted by circulating a fluid through buried "ground loops" to address space/water heating demands. Conversely, the system can discharge waste heat back into the ground or water as energy storage to address cooling demands (EnergyGuide, 2004). A skyscraper's footprint and surrounding site dictate the use of extraction at deeper boreholes or integration with foundation piles (Parker & Wood, 2013), which is demonstrated in projects such as the Porta Nuova district's four geothermal heat pumps in Milan, Italy, which service Bosco Verticale's residential towers, taking advantage of the city's underground aquifer to address the tower's heating/cooling demands simultaneously (Smith, 2015).

While ground-source energy is used in a variety of projects, sky-sourced energy – except for solar and wind – has not yet been researched comprehensively (Leung & Weismantle, 2008). Harnessing the full potential of sky-sourced energy – induced by variation in environmental factors along building height – can provide extended opportunities for energy savings and generation. Incorporating these variations as part of skyscraper's early design stages, simulation, and analysis can have a significant impact on the overall building heating/ cooling distributions. This is demonstrated in the computational analysis of the Freedom Tower (2014) located in New York and designed by SOM (see Fig. 2). By accounting for height-induced environmental variations of temperature and wind effect changes only, a 13 percent difference was identified in total annual building cooling/heating energy loads between the ground and top floors of the tower. The design team, however, didn't account for variations such as air pressure, density, and moisture, which could have increased the energy-load's percentage difference (Simmonds, 2015). Hence. multiple opportunities for energy savings and generation can be created by exploiting the environmental effects of height in skyscrapers.

Figure 2. Freedom Tower, New York. (Source: Dolby, 2014).

2.4. Generation

The integration of renewable energy generation systems requires a rigorous exploration for ideal system configuration, cost mimization, maximized system reliability and financial return, in addition to cooperative agreements with local policies to capitalize on peak time generations (Baños et al., 2011). Moreover, these parameters are explored in the context of fluctuating environmental influences. The complexity of the integrated systems increases when exploring multiple renewable systems to perform symbiotically (Turrin et al., 2011). Consequently, few renewables can compete with fossil-fuel-reliant systems, with an economic viability limited to certain locations, climatic conditions, and a prerequisite of a grid connection (Zangeneh et al., 2009).

2.4.1. Photovoltaics

One of the contending renewables is Photovoltaic (PV) technology, which has immense potential for façade integration in skyscrapers, given the skin area-to-volume ratio. For example, 7,244 PV panels are integrated on the 118-meter-high CIS Tower's façade located in Manchester, UK (see Fig. 3), and is estimated to generate 180,000 KWh annually (Kareem & Zuo, 2012). Geographic location and climatic conditions, however, result in great differences in PVs efficiency and electrical output. For example, an integrated mono-crystalline PV panel in a skyscraper in London or Moscow can yield 111-119 KWh/m^2/year, which is only half of what a similar panel mounted on a project in Delhi, Los Angeles, or Cape Town could generate (233 KWh/m^2/year) (Al-Kodmany & Ali, 2013). Hence, for competitive renewable energy system integration, a holistic optimization is imperative, starting in the early architectural design phase.

2.4.2. Combined Heat and Power (CHP)

Another critical onsite energy generation system is Combined Heat and Power (CHP), which couples the generation of electricity with usable heat energy, and Tri-Generation, which is the triple generation of electricity, heat energy, and cooling through an absorption chiller (Parker & Wood, 2013). CHP plants can be bio-fueled by organic waste materials, which is particularly appealing if the building has integrated vertical farming. CHP systems can be highly efficient in both electricity and heat energy generation; however, it is a characteristic of CHP systems to generate undesirable excess heat energy (Ali & Al-Kodmany, 2012), which requires further design considerations for transfer into energy storage. The Shard (2013) located in London, UK and designed by Renzo Piano, is a clear demonstration of the successful integration of a large-scale CHP plant, capable of generating 1.131 MW of electricity and 1.199 MW of hot water at 85 percent efficiency (ClarkeEnergy, 2012).

2.4.3. Wind Power

In recent years, the skyscrapers integrating wind-turbine technology have been optimized by pioneering strategies,

Figure 3. CIS Solar Tower, Manchester, UK: a skyscraper covered in solar panels (Source: Mikey, 2010).

such as shaping the roof to accelerate ambient winds through an array of multiple wind turbines mounted in ducts, and/or designing the building profile to accelerate the ambient winds on fewer, yet larger turbines (EL-okadem et al., 2015). Despite concerns of safety, inefficient energy yields and coverage ratios, skyscrapers optimized for wind power can have increased wind energy output from tapping into high-energy-content winds at high altitudes and the extended benefits of decreased structural wind loading requirements due to the aerodynamic form (Frechette & Gilchrist, 2008).

According to Stankovic et al., the wind turbines' output power equation is identified as P-Turbine= CP*1/2*ρAV3 (Stankovic et al., 2009). The coefficient of performance (CP), which is typically 0.3, relies on the turbine type. Air density (ρ) is directly proportional to the turbine's energy output. Since air density decreases with high altitudes, this factor can be crucial when considering optimum turbine placement along the tower height. Swept area of the blade (A) is critical, as doubling (A) can double the energy output. Velocity (V) is the most important variable in this equation. According to Terri Boake, wind turbine output is a cube of the utilized wind speed (Boake, 2014). Current research in the computational optimization of blade design promises significant improvements in extracting the kinetic energy from the prevailing winds.

Another critical concern in skyscraper's integrated wind turbines is the outdated turbines technology which inhibits the building from fully harnessing the abundant energy stream; however, advancements in the field of CFD allow simulations of aerofoils in the third and fourth dimensions (Fig. 4), providing designers with a better understanding of the consequential implications of their designs, such as blade interaction with prevailing winds and better control over the overall integrated wind turbine systems (Stankovic et al., 2009). The Pearl River Tower, Shenzhen, demonstrates a successful aerodynamic geometric optimization for improved integrated wind turbines' yields (Tomlinson-II et al., 2014). Performance-optimization strategies included funneling the ambient winds through four channels – embedded into the mechanical floors to conserve usable space – increasing the ambient wind speed by a factor of two to 2.5 times (Frechette & Gilchrist, 2008). While wind generation accounts for a relatively small part of total energy consumption, this strategy symbiotically created a more efficient structure, reducing the structural wind-loading requirements (Boake, 2014).

3. Multi-Objective Optimization and Genetic Algorithms

Computational generative systems such as MOO have enabled designers to pursue the concept of form-finding rather than form-making, which is steered by embedded performance-based morphology over time (Kolarevic & Parlac, 2015). To achieve a variety of optimized design solutions based on the embedded design criteria, the MOO process requires first determining the key performative

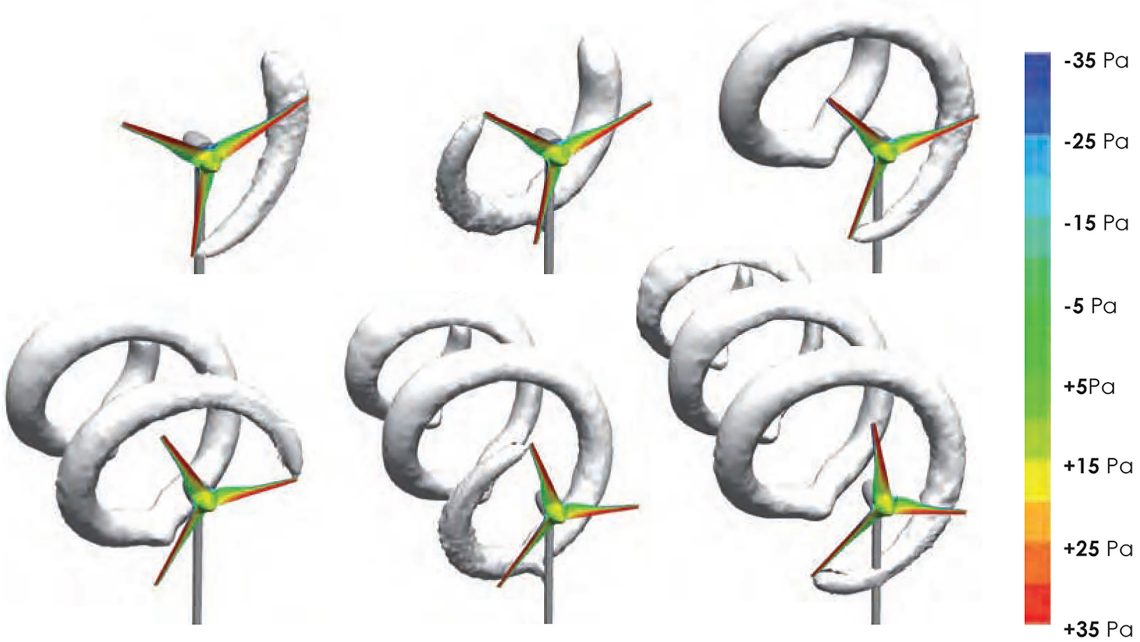

Figure 4. Animated frames of a wind turbine simulation, depicting the pressure on blades and the resulting dynamic movement from tracing smoke from the blades (Source: Stankovic et al., 2009).

parameters critical for the selected project, and subsequently, computing a balance between various, often conflicting performance parameters (Ashour & Kolarevic, 2015). Genetic algorithms (GA) – which can be used as the solution engine in MOO – are part of the Population-based algorithms family, which have been extensively employed for energy-flow optimization through the evaluation of multiple alternatives of generated energy distribution and efficiency protocols (Cai et al., 2009). Population-based evolutionary algorithms include genetic algorithms, ant colony systems, memetic algorithms, and particle swarm. Genetic algorithms have been particularly successful in the built environment for their inherent cycle-based search technique. By exploring "populations" of design solutions, optimized progression shifts to the resulting solutions offspring. Thus, the resulting design outcomes (Fig. 5) perform best relative to the predefined design criteria "fitness function" (Baños et al., 2011).

4. Other Generative Resources

4.1. Vertical Farming

The generation of agricultural crops through vertical farming can have immense advantages (Despommier, 2010). This method is particularly useful in high-density city centers, where high land prices prevent farming activities in a traditional open land setting. Moreover, because of vertical farming's inherent year-round production, controlled indoor environment and use of NASA's developed dwarf plant agriculture, one acre (0.4 hectares) in a vertical farm can yield the equivalent of four to six acres (1.6 to 2.4 hectares) of traditional open-land farming (Despommier, 2009). This margin can increase to 30 times, depending on the type of crops produced (Despommier, 2010). Furthermore, this yield is exempt from extra losses due to transportation. Projects such as the Pasona Headquarters (Fig. 6) located in the Ginza district of Tokyo, Japan, are examples of this technology's potential (konodesigns, 2010).

It is essential to be mindful of the limited and valuable space available within skyscrapers; therefore, space allocated to integrate generative systems, such as vertical farming, must be rigorously designed. For example, vertical farming can be provided in sky gardens or within a multi-skin façade. For an enhanced system yield, vertical farming requires further optimization of the operational farming system. This optimization needs to streamline the input flow of irrigation, and daylight penetration from fenestration (Despommier, 2010), and similarly, the output flow of recycling irrigation water and the direction of solid waste for potential energy generation via onsite CHP plant.

4.2. Fog Harvesting

One of the most promising, yet under-researched (particularly in skyscrapers), water-harvesting technologies is fog harvesting. This particular type of water harvesting depends on air moisture, density, and directed wind flow. These parameters – which vary with height – can be optimized via CFD analysis (Leung & Weismantle, 2008). This inexpensive technology uses polypropylene meshes to harvest water through a passive impaction process, rather than via active condensation (Schemenauer & Cereceda,

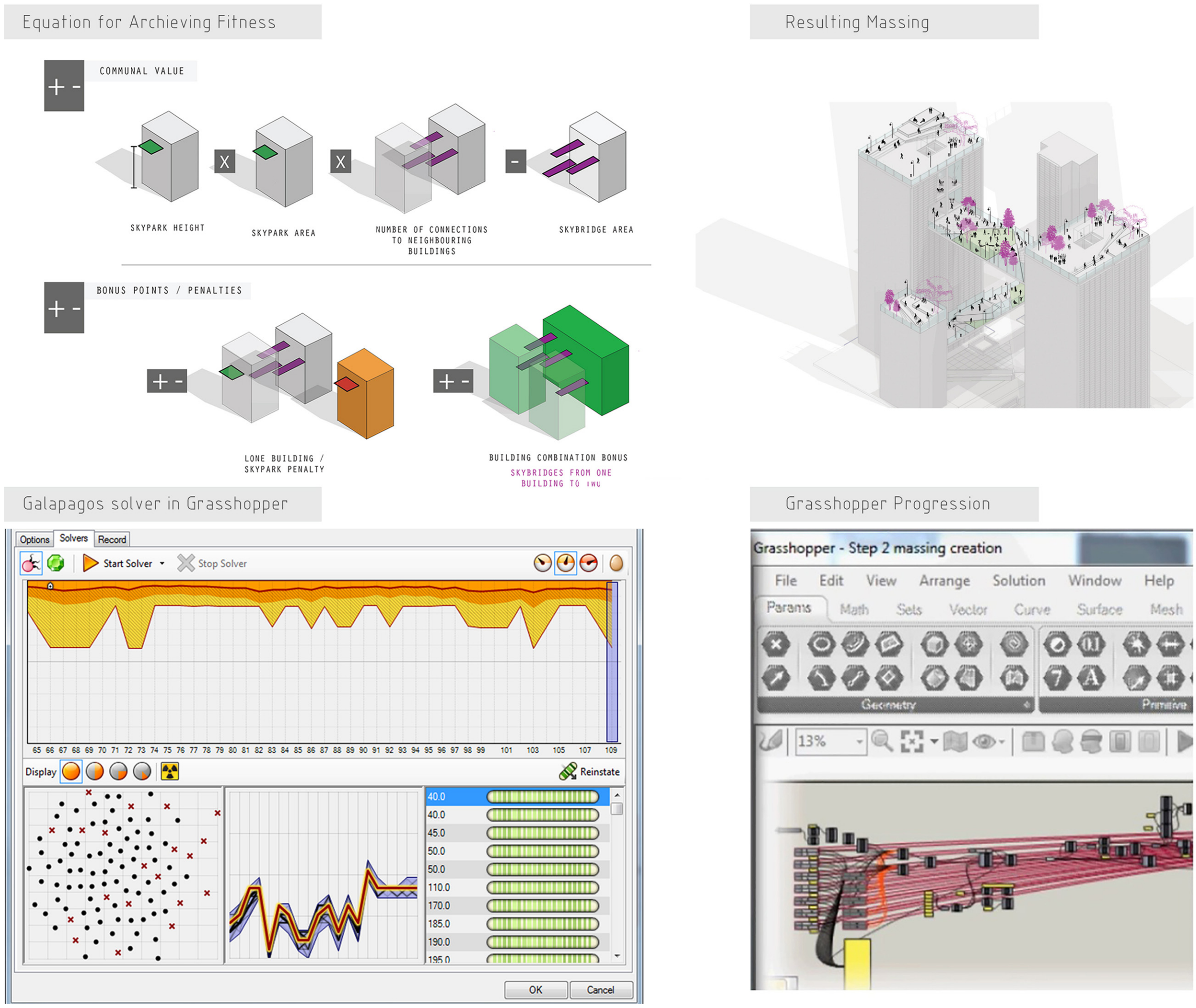

Figure 5. Illustration of using Grasshopper and Galapagos Plugins for form finding, based on an identified fitness function. (Source: Paul Wintour, 2015).

1994). This technique of water harvesting has been rigorously tested in various coastal highlands across the world. According to the non-profit organization Fog Quest, small-scale fog harvesting facilities (Fig. 7), such as in Chile, Yemen, Morocco, and elsewhere, show great promise, as yields from a standard 40-square-meter collector can reach a maximum of 2,000 L/day. The yields, however, can potentially average to 200 L/day across the year (FogQuest, 2015). These projects prove the viability of fog harvesting as a water source in various locations across the world. If calibrated to simultaneously accommodate rainwater harvesting, this passive technology can potentially be of further significance in the design of tall buildings.

5. Conclusion

This paper argues for the optimized integration of large-scale resource production systems as essential for the evolution of the next generation of skyscrapers. RGS performance improvements and generative potential can be enhanced using the evolutionary tools of MOO and GA coupled with evaluation tools, such as CFD and EnergyPlus®. Using these tools, a designer can visualize and explore the multi-resource, multi-system generation optimization of parameters such as energy, food, water, and land (Fig. 8). The initial focus must be on waste-energy harvesting capabilities by exploring (1) passive features of integrated active renewable systems; (2) the harnessing of sky-sourced energy, which can highlight extended opportunities for energy savings and generation; and (3) calibrations for optimized building footprint and height range – relative to location and context – to achieve a balance between energy consumption and generation.

Some of the key milestones essential to the tall building advancement process are the optimization of synergetic, multi-system, on-site generation supplies; systems capa-

Figure 6. Pasona Headquarters, Tokyo, showing vertical farming activities on the façade (Source: 螺 , 2011).

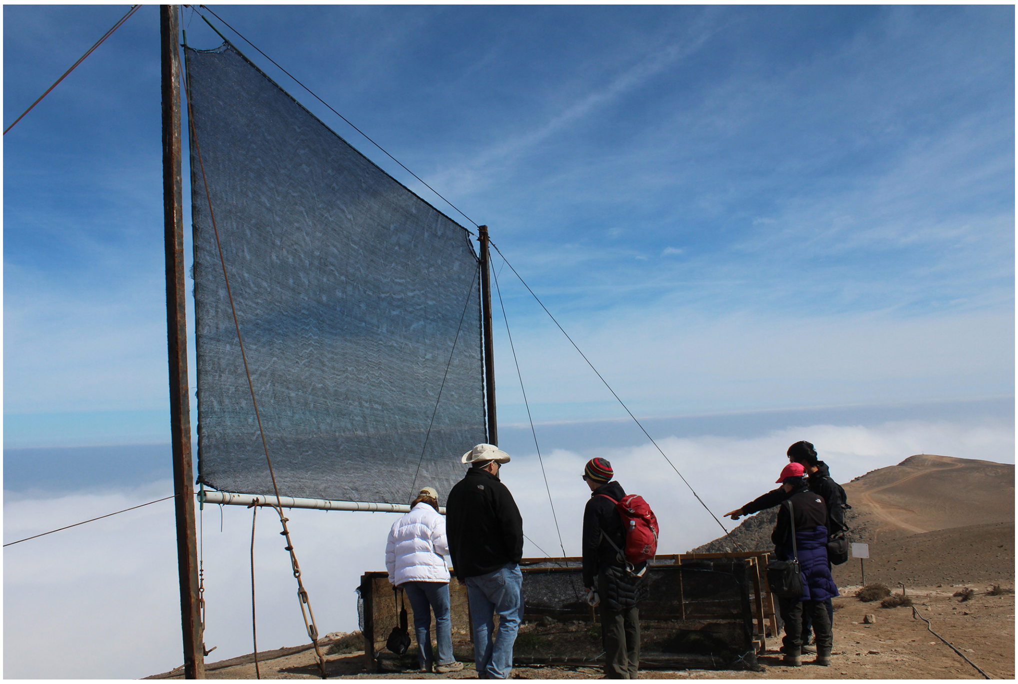

Figure 7. Fog harvesting mesh in Alto Patache, Atacama Desert, Chile (Source: Pontificia Universidad Católica de Chile, 2013).

ble of storing generated energy; and a reliable, secure connection to the grid, which can be explored by the computational design aid tools of MOO and GA highlighted in this paper. These tools can be calibrated to simultaneously optimize other aspects of the skyscraper's performative profile: such as daylighting, heat control, glare, views, privacy, façade-integrated solar energy generation or natural/mixed-mode ventilation, form aerodynamics, wind power generation, urban agriculture, CHP system flow, and the impact on the surrounding environment.

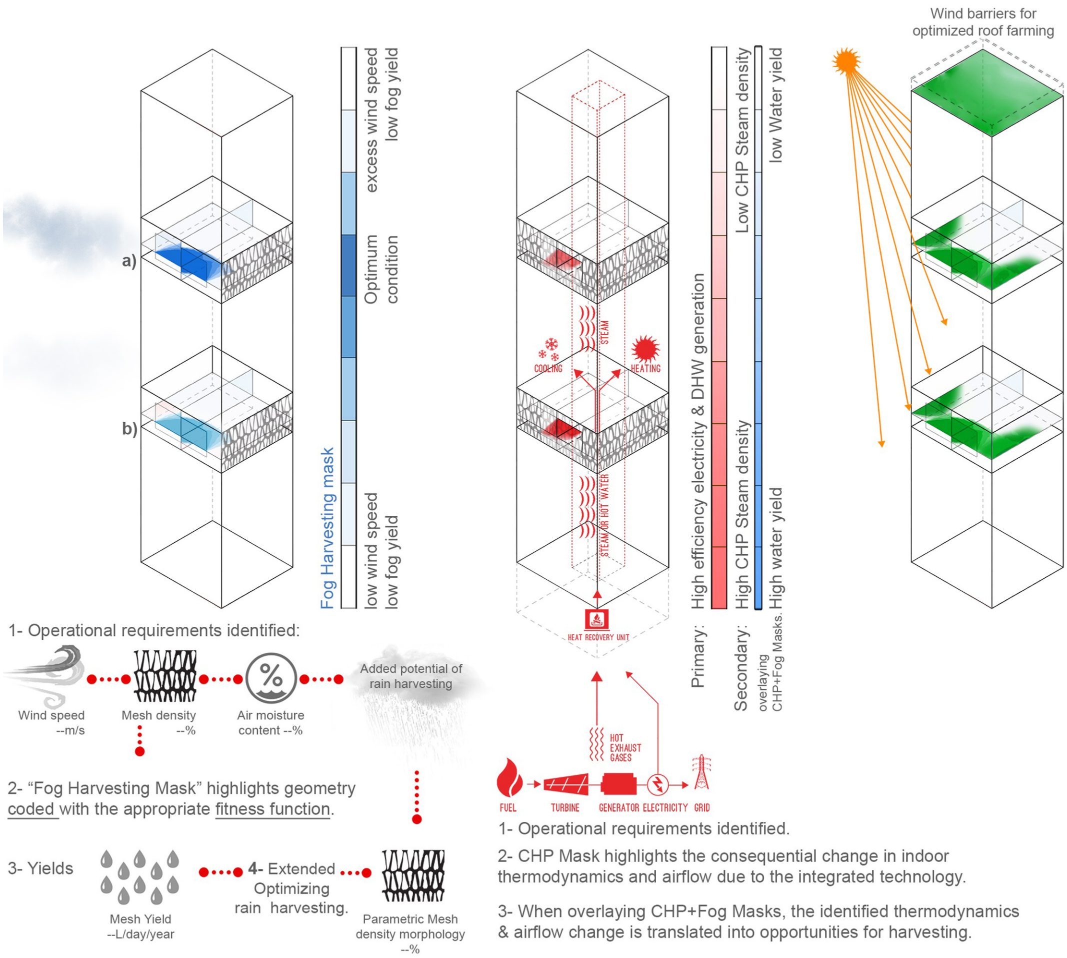

Figure 8. Demonstrating the potential multi-resource, multi-system generation optimization process. (Source: Author)

References

Ali, M. M. and Al-Kodmany, K. (2012). "Tall Buildings and Urban Habitat of the 21st Century: A Global Perspective." Buildings-Open Access Journal, pp. 384-423.

Al-kodmany, K. (2012). "The Logic of Vertical Density: Tall Buildings in the 21st-century City." International Journal of High Rise Buildings, Volume 1, number 2.

Al-Kodmany, K. and Ali, M. M. (2013). The Future of the City: Tall buildings and Urban Design. S. l.: WIT Press.

Ashour, Y. and Kolarevic, B.. (2015). "Optimizing Creatively in Multi-objective Optimization." Symposium on Simulation for Architecture and Urban Design, pp. 59-66.

Baños, R. et al. (2011). "Optimization Methods Applied to Renewable and Sustainable Energy: A Review." Renewable and Sustainable Energy Reviews, Volume 15, Issue 4, pp. 1753-1766.

Boake, T. M. (2014). "Closing the Gap between Fantasy and Reality: Pushing Current Technologies into the Future." CTBUH, Issue III, pp. 34-39.

Cai, Y., Huang, G., Tan, Q., and Yang, Z. (2009). "Planning of Community-scale Renewable Energy Management Systems in a Mixed Stochastic and Fuzzy Environment." Renewable Energy, pp. 1833-1847.

Cichy, M. J (2012). Energy Efficiency of Tall Buildings: Practical Methodology for Integrated Design. Auckland: The University of Auckland. ClarkeEnergy. (2012). The Shard Combined Heat and Power Plant. Available at: https://www.clarke-energy.com/2012/the-shard-combined-heat-and-power-plant/[Accessed 13 07 2015].

Despommier, D. (2009). Scientific American. A Plan for a Sustainable Future, How to get all energy from Wind, Water and Solar power by 2030, 11. pp. 80-87.

Despommier, D. (2010). The Vertical Farm. New York: Thomas Dunne Books.

Drew, C., Nova, K. F. and Fanning, K. (2015). "The Environmental Impact of Tall vs Small: A Comparative Study." International Journal of High-Rise Buildings. pp. 109-116.

Ellis, P. and Torcellini, P. (2005). Simulating Tall Buildings Using EnergyPlus. National Renewable Energy Laboratory, Golden, CO, USA.

EL-Mokadem, A. A., Megahed, N. A., and Noaman, D. S. (2015). Systematic Framework for the Efficient Integration of Wind Technologies into Buildings. ELsevier.

EnerGuide. (2004). Heating and Cooling with a Heat Pump. s.l.: Natural Resources Canada's Office of Energy Efficiency.

Ewing, R. et al.. (2008). Growing Cooler: Evidence on Urban Development and Climate Change. The Urban Land Institute: Washington, D.C. FogQuest. (2015). http://www.fogquest.org/Available at: http://www.fogquest.org/videos-information/figquest-manual/ [Accessed 29 07 2015].

Frechette, R. and Gilchrist, R. (2008). Towards Zero Energy: A Case Study of the Pearl River Tower, Guangzhou, China. Dubai, Council on tall buildings and urban habitat.

Gustavsson, J. and Cederberg, C (2011). Global Food Losses and Food Waste. Available at: http://www.fao.org/ docrep/014/mb060e/mb060e00.pdf [Accessed 01 07 2015].

Kareem, A. and Zuo, L. (2012). "Energy Harvesting and Motion Control of Tall Buildings Using Tuned Mass Dampers." CTBUH 2012 9th World Congress, Shanghai, pp. 351-357.

Ko, D.-H., Elnimeiri, M. and Clark, R (2008). Assessment and Prediction of Daylight Performance in High-Rise Office Buildings. CTBUH/ Wiley Tall Journal.

Kolarevic, B. and Parlac, V (2015). Building Dynamics: Exploring Architecture of Change. s.l.:Routledge.

Konodesigns. (2010). Pasona Group Urban Farm. Available at: http://konodesigns.com/portfolio/Urban-Farm/ [Accessed 13 03 2016].

Leung, L. and Weismantle, P (2008). How Supertall Buildings Can Benefit from Height. Dubai, Council on Tall Buildings and Urban Habitat Papers.

Li, L., Shen, X. and Qian, R (2015). "Typological Evolution of High-rise Buildings in Terms of Thermodynamics and Energy Formation." International Journal of High-Rise Buildings, Volume 4, Number 2, pp. 127-133.

Malkawi, A. M., Srinivasan, R. S., Yi, Y. K., and Choudhary, R. (2004). Performance Based Design Evolution: The Use of Genetic Algorithms and CFD. Elsevier, pp. 33-44.

Newman, P (1996). "Reducing Automobile Dependence." Environment and Urbanization, Vol. 8, No. 1, pp. 67-91.

Nordenson, G. and Riley, T (2003). Tall Buildings. New York: Museum of Modern Art.

Oldfield, P., Trabucco, D. and Wood, A (2009). "Five Energy Generations of Tall Buildings: An Historical Analysis of Energy Consumption in High-Rise Buildings." The Journal of Architecture, Volume 14, Number 5, pp. 591-610.

Oldfield, P., Trabucco, D., and Wood, A (2014). Roadmap on the Future Research Needs of Tall Buildings. Council on Tall Buildings and Urban Habitat.

Parker, D. and Wood, A. (2013). The Tall Buildings Reference Book. Abingdon: Routledge.

Roaf, S., Crichton, D. and Nicol, F (2009). The End of the Age of Tall Buildings. In: Adapting Buildings and Cities for Climate Change: A 21st Century Survival Guide. Burlington, MA, USA: Elsevier Ltd., pp. 237-265.

Schemenauer, R. S. and Cereceda, P (1994). "A Proposed Standard Fog Collector for Use in High-elevation Regions." Journal of Applied Meteorology- Volume 33, pp. 1313-1322.

Simmonds, P (2015). ASHRAE Design Guide for Tall Supertall, and Megatall Building Systems. Atlanta: ASHRAE. Smith, A (2015). CIBSE Case Study: Garden City. CIBSE.

Stankovic, S., Campbell, N. and Harries, A (2009). Urban Wind Energy. London: Earthscan.

Tomlinson-II, R. et al.. (2014). "Pearl River Tower, Guangzhou." CTBUH 2014 Issue II.

Turrin, M., Buelow, P. v. and Stouffs, R (2011). "Design Explorations of Performance Driven Geometry in Architectural Design Using Parametric Modelling and Genetic Algorithms." ELSEVIER, pp. 656-675.

UN. (2014). World Urbanization Prospects. New York: United Nations, Department of Economic and Social Affairs.

Watts, S. and Langdon, D (2010). Tall Buildings in Numbers. Available at: http://www.ctbuh.org/LinkClick.aspx?fileticket=rJbb7oNXnZw%3D&language=en-GB [Accessed 29 09 2015].

Weismantle, P. and Stochetti, A (2013). "Case Study: Kingdom Tower, Jeddah." CTBUH journal 2013 Issue I.

Wood, A. (2013). Why Build Tall? In: The Tall Buildings Reference Book. Abingdon,: Routledge, pp. 10-32.

Wood, A. (2015). 100 of the World's Tallest Buildings. s.l.: Images Publishing.

Zangeneh, A., Jadid, S. and Rahimi-Kian, A (2009). "Promotion Strategy of Clean Technologies in Distributed Generation Expansion Planning." Renewable Energy, Volume 34, Issue 12, p. 2765-2773.