NOVUS ENVIRONMENTAL

Environmental Challenges in Vertical Healthcare Design

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In 2016 the Chicago Committee on High Rise Buildings hosted a seminar entitled "The Rise of the Urban Hospital: High Rise Healthcare Facilities for the 21st Century". It was the first gathering of its kind focussing on current technologies and future research needs for the design of high-rise hospitals. The program included discussions with some of the world's high-rise building design experts and featured topics such as code impacts, lift systems, exterior enclosures and elements of MEP design. It was a great opportunity to share insights on some of the vital elements of a functional hospital, such as wayfinding, life safety and critical support systems, and how these elements may need to be reconsidered in a vertical healthcare environment[1].

The design of a vertical healthcare environment presents a number of interesting challenges related to acoustics, vibration, air quality, and the microclimate. While the impact of acoustics and indoor environmental quality on patients and staff has received a great deal of attention over the past 10 years, and are now commonly accepted design considerations, designs that consider the effects of wind and the microclimate are perhaps less common. However, these elements can be equally important to the quality of healthcare delivery at many sites. Indeed, for a high-rise hospital located in a dense urban setting, the effects of wind and climate can be amplified compared to more open rural settings.

Following the CCHRB seminar, I sat down with a few of my colleagues to discuss some of the key challenges that we have encountered in the design of vertical healthcare environments. In this paper we offer our insights on design issues and strategies related to environmental factors in the midst of increasingly vertical healthcare facility design.

Three Key Influencers

The impact and significance of each environmental factor can be determined by what we refer to as the three key influencers: *the urban setting, the condensed footprint and the building height.*

1. **The urban setting:** the desire to build vertical is often a result of land availability and cost, which places the high-rise hospital in a dense urban environment. The facility is situated in the core, surrounded by busy streetscapes, close neighbors and mixed demographics.
2. **The condensed footprint:** the urban site constrains the facility to a small footprint compared to the vast expanse of the many health campuses of the world. This produces less forgiving and less flexible stacking as the pieces of the puzzle are fit to the available square footage.
3. **The building height:** forcing the program skyward introduces challenges and opportunities. These relate to structure, mechanical systems and the effects of wind and climate at higher elevations.

With each of these influencers in mind, let's discuss some key challenges related to air quality, acoustics, vibration, and the microclimate.

Air Quality

For input on challenges related to air quality I turned to Novus Principal Jason Slusarczyk, whom has spent the last 15 years of his career solving problems related to exhaust dispersion and ventilation design in healthcare facilities.

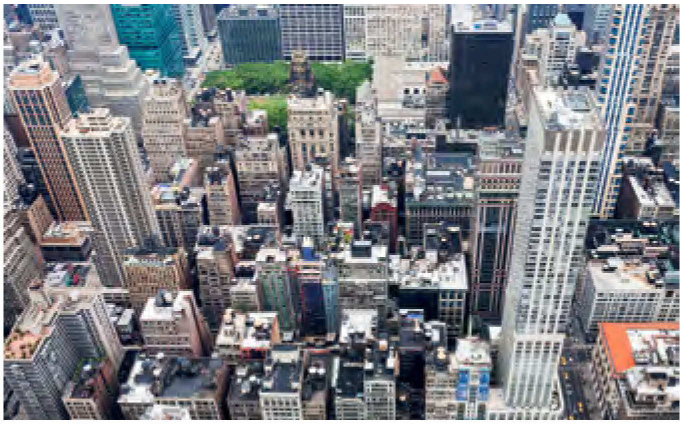
> **"In healthcare environments the discussion on air quality is often centred on odor and entrainment of building-related exhaust at air-sensitive receptors... These receptors include areas such as fresh-air intakes, outdoor therapy spaces and open doors and windows on the facility."**

The interaction of site winds with the building form lead to development of recirculation zones wherein exhaust from generators, idling trucks, laboratory stacks and other sources is re-directed back toward the building instead of being ejected skyward, away from the building. These exhaust plumes can get trapped in a recirculation bubble on the rooftop, formed as wind blows up and over the face. "The primary issue is impacts on IPC (infection prevention and control) and patient health. The second issue is the potential for occupants to detect odors from various sources at the facility", adds Jason. "The odorous fumes make their way to a fresh-air intake and then in to the building. I've worked on facilities where surgeons could smell freshly cut grass in the OR due to unfortunate placement of an intake louver. Needless to say, the conditions were not conducive to a functional surgical environment."

I asked Jason to relate his thoughts on air quality challenges in high-rise hospitals according to the three key influencers.

THE URBAN SETTING

In urban centres land is scarce and you are hard pressed to find a safe, well-ventilated area to place your helipad. It is typically placed on the roof above the mechanical penthouse with a line-of-sight to neighboring buildings. When the helicopter lands or takes off, exhaust fumes are pushed downward. This downwash can wreak havoc on air-sensitive receptors such as fresh-air intakes on your building or



The clutter of building equipment on rooftops largely goes unnoticed from the ground, but noise and exhaust emissions from these equipment can have significant impacts on health and indoor environmental quality in high-rise hospitals due to their exposure to fresh air intake systems and outdoor spaces at upper elevations.

on your neighbor's property. Controlling entrainment of downwash requires an understanding of the interaction of site winds with the buildings and strategic placement of the helipad and fresh air intakes. A downtown location usually means a lot of close neighbors and perimeter roadways. These can be significant sources of contamination at fresh-air intakes and other openings (entrances, windows etc.). Placement of these intakes and openings should account for the locations of these sources and the interaction of site winds with the building, for controlling entrainment of odors and other contaminants that will affect indoor air quality.

THE CONDENSED FOOTPRINT

Due to the condensed building footprint, high-rise hospitals often feature mid-level mechanical floors that house air handling equipment. Fresh-air intakes at these mid-level elevations are exposed to roadway sources (e.g., diesel trucks and buses), in addition to any rooftop sources on neighboring buildings at lower elevations. Exhausts from these sources travel upward and can be directed in to the building fresh air supply.

In high-rise hospitals, ambulance and loading bays are commonly located beneath the building, at street level. Without sufficient dispersion, vehicle exhausts can be 'trapped' in these areas and drawn in to nearby intakes. A common misconception is that in 'windy cities' these sources will be easily dispersed. In reality, the complex interactions between site winds and the building may result in very little dispersion and potential problems.

Wind tunnel tracer gas testing is used to assess the potential for building exhaust to enter the building through fresh air intakes and other openings. On high-rise hospitals downwash from helicopters is a particular concern. The photo at left illustrates how exhausts can be directed downward due to the recirculation bubble formed over the rooftop.

BUILDING HEIGHT

In addition to the above issues, which relate to building height as much as they do to the urban setting and condensed footprint, vertical environments can produce onerous requirements for building exhaust systems. Generators, which are often located at grade due to their size, weight and fuel storage requirements, are significant sources of odor and in some cases, for diesel fired units, contaminants that can compromise health. Effective dispersion requires combustion exhaust stacks be routed upward, above the rooftop. This can be costly and will impact other facets of the design, so must be carefully evaluated and should be addressed in early planning stages.

Healthcare facilities typically require weekly exercising of emergency power systems, which means relatively frequent emission of combustion exhaust to the atmosphere. This frequency of occurrence, together with the frequency of problematic winds are primary considerations for the design of air quality controls on generators.

Located in downtown Chicago, the **Ability Institute at the Rehabilitation Institute of Chicago** ranks 12th on the CTBUH's list of the world's tallest hospitals[2]. Wind tunnel tracer gas tests were conducted to assess dispersion of combustion exhaust from emergency generator systems. Photo at left courtesy of http://skyrisecities.com/news/2015/12/photos-show-ability-institute-ric-exterior-nearly-complete

Acoustics

For insights on acoustics I turned to my colleague Darron Chin-Quee. Darron has provided guidance on acoustics, noise and vibration design for healthcare facilities throughout North America and parts of the world for over 25 years.

> **"In vertical healthcare environments there are competing acoustic environments that result from stacking of noisy and sensitive spaces, exposure to exterior urban sources of noise, and the complexity of building services."**

"Our job, in light of this competition, is to create comfortable acoustic environments, free from noise disturbance and conducive to rest and recovery, while adhering to the complex programming of a vertical healthcare environment. The fatiguing effects of noise cannot be overlooked from the perspective of staff comfort and turnover."

Darron relates his thoughts on acoustical challenges in high-rise hospitals according to the three key influencers.

THE URBAN SETTING

We've all experienced the noisiness of an urban core. Sirens, horns, urban rail, and rooftop equipment are common sources of noise emissions in cities. When you combine these sources with the highly reflective concrete and glass canyon of city streetscapes that channel the noise quite effectively, you arrive at some important considerations for the design of the building shell.

Many of the noise-sensitive spaces in a healthcare facility are on the perimeter of the building, and directly exposed to exterior noise (e.g., patient beds, treatment space for ASD, sleep etc.). The shell must be designed to limit noise ingress from the exterior, and satisfy acoustic performance criteria, together with requirements for daylighting and views. Typically the glazing is the acoustically weak component, and selection of an assembly with appropriate sound transmission loss characteristics is important to preserving sound isolation.

Medivac helicopters landing on rooftop helipads are a significant source of exterior noise in urban settings. Due to their low-frequency noise signature, acoustic controls may be more substantial than those required for roadway sources and building equipment. Added mass, thicker glazing and acoustic buffering (separation) are effective measures to consider.

Helipads located on rooftops above noise-sensitive areas may require customized acoustic treatments to control noise disturbances.

CONDENSED FOOTPRINT

Limitations on space usually means that the central plant will be located within the building footprint, stacked above and/or below acoustically-sensitive areas — bringing noisy services in proximity to quiet areas. Careful space planning is an effective first line of defence to avoid stacking between noisy spaces (e.g., chiller rooms, generators) and quieter areas. Sound isolation of the plant space will require a sufficiently thick floor separation, in addition to treatments that can eat up ceiling space. Where noisy spaces stack above quiet areas, a floating (secondary) floor construction may be necessary. This can have implications on structural loads and detailing of floor, wall and ceiling assemblies. Because of the impacts on space, input on these control elements should be obtained early in the design of the building.

BUILDING HEIGHT

For some sources of noise disturbance, a taller building can be beneficial. Rooftop noise sources are elevated, with potentially improved separation from internal spaces. For example, cooling towers, condensing units and generators can be located on a rooftop above quieter air handling system space that stacks above occupied areas. In this configuration, the air handling plant acts as a sound isolation buffer, controlling noise transmission through the roof to occupied areas.

Roadway noise will generally be lower at higher elevations, reducing the sound isolation requirements of the envelope. However, noise emissions from equipment on neighboring rooftops, or low rooftops on the facility itself, can be a concern and should be evaluated.

The **Ann & Robert Lurie Children's Hospital** in Chicago features a number of unique stacking arrangements, included an Emergency Department located on the second floor above the ambulance bay, medical imaging on the fifth floor and a Sky Lobby and Conference Centre on the eleventh floor. Control of noise ingress from a nearby fire station was an important consideration for the acoustical design of the building. At the time of writing it ranks 9th on the CTBUH's list of the world's tallest hospitals.

Vibration

In healthcare facilities, structural vibrations can impact the performance of imaging equipment and other high-resolution procedure or surgical spaces.

The primary vibration sources of concern are occupant footfalls, building equipment and environmental sources (neighboring buildings, roadways etc.). Mitigation strategies for each source vary, but typically are targeted at a combination of source, transmission path, and receiver control elements.

In a vertical healthcare environment, there is some added complexity for vibration design compared with traditional settings, which are due to the three key influencers.

URBAN ENVIRONMENT

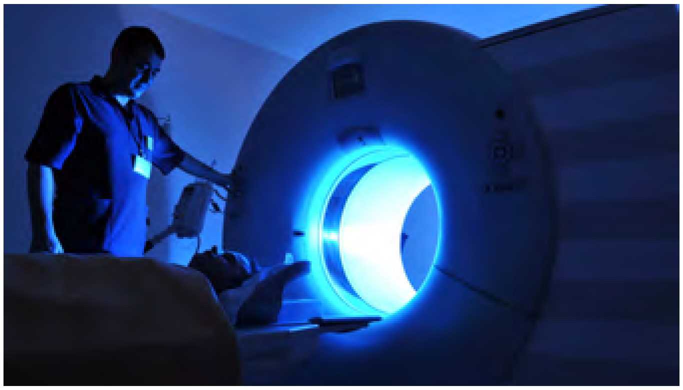
Ground vibrations from road and rail traffic are more prevalent in urban settings, and can be a significant source of concern for the vibration design of a healthcare facility. Typically only the

The Centre hospitalier de l'Universite de Montreal (CHUM), shown in the foreground, includes a medical research facility that straddles a six-lane freeway, subway system and is surrounded by perimeter roads. Control of ground-borne vibration impacts on imaging equipment was a key aspect of the vibration design of the building. CHUM ranks 36th on the CTBUH list of the world's tallest hospitals. Image courtesy of http://www.cannondesign.com/our-work/work/centre-hospitalier-de-luniversite-de-montreal/

first few floors would be affected by ground-borne sources, and as such, a control strategy might include locating sensitive spaces at higher elevations. However, this approach should be weighed against demands on floor systems to control footfalls and the effects of building sway. Low-frequency lateral motions of the building under wind loads can affect image quality obtained from research and diagnostic equipment.

CONDENSED FOOTPRINT

A condensed footprint can place ambulance and loading bays at street level, possibly beneath the building. As a result, vibration-sensitive medical equipment, which are typically best sited slab-on-grade, must be installed on supported structure above street level. This increases susceptibility to disturbances from occupant footfalls, building sway and other structure-borne vibrations, which are usually less insignificant at slab-on-grade locations. Consequences include deeper structural systems for support of sensitive equipment and impacts on ceiling height below. Vibration isolation of these equipment may necessitate integration with the architectural and structural designs, requiring careful attention to detailing and consideration of additional loading.



In high-rise healthcare facilities vibration-sensitive equipment such as MRI are typically located on upper floors. This introduces structural challenges for vibration control, as well as architectural challenges for noise control, particularly in steel-framed structures.

Vibration challenges can also arise in areas not associated with equipment and procedures. During the design of one high-rise hospital, multi-purpose space on the 11th floor was considered for periodic use as fitness space for staff. The result would be higher-than-expected dynamic loads on the floor system, potentially perceptible motions from rhythmic activities, and noise disturbances to contiguous quiet areas. Dedicated space at ground level, or in areas well-buffered from noise and vibration sensitive areas are effective solutions in traditional hospital settings, but may not be accommodated in a high-rise.

Finally, the condensed footprint in an urban setting necessitates multi-story parking, which is often integrated into the lower portion of the building or below ground. In such cases, it is important to consider the separation between the garage and vibration-sensitive areas. Based on our experience with measurements of vibrations from parking garages, imaging equipment should be placed a minimum of two floors above or below the garage so that there is sufficient attenuation of vehicle vibrations by the structure. When this separation cannot be accommodated, additional design measures that include controls at source (e.g., speed limits, exclusion of speed bumps), controls along the path (e.g., structural 'de-tuning', isolation/decoupling of structure, strategic layouts), and controls at the receiver (e.g., equipment isolation platforms), may be necessary.

BUILDING HEIGHT

Building sway due to the action of wind can affect image quality from equipment such as high resolution microscopes. Since sway movements increase at higher elevations, locating equipment on lower floors can be an effective first step to control. However, this must be balanced with potential impacts from ground-level sources or parking garages, and the needs of the healthcare program. Any vibration concerns related to imaging equipment located on upper floors should be evaluated by a vibration consultant and should include discussions with the vendor.

Microclimate

For his thoughts on challenges related to wind and climate I turned to Novus' Senior Microclimate Specialist Bill Waechter. Bill has spent the last 40 years working with architects, providing them with design solutions related to wind and thermal comfort in outdoor areas and safety and maintenance issues related to stack effect and snow drifting in northern climates.

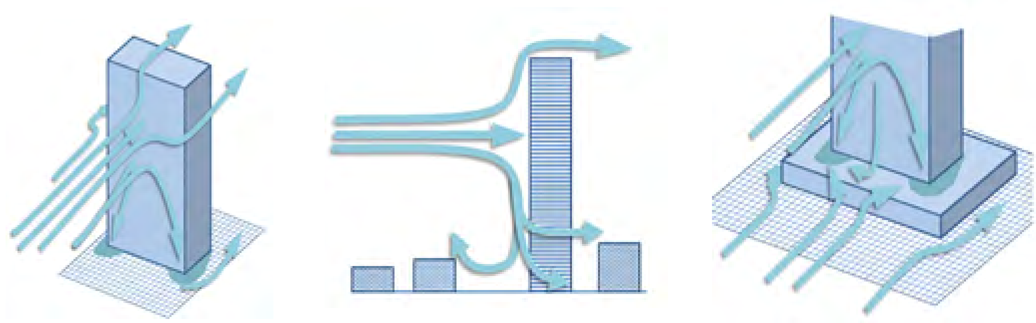
> **"Tall buildings produce a number of wind and climate related challenges that extend beyond structural design and energy demands. The complex interaction of site winds with the building form generates conditions that can affect the comfort and safety in outdoor areas, as well as within."**

The interplay between building form and the microclimate produces conditions unique to every project and every site. Key issues such as wind comfort, stack effect, falling ice and snow, to name a few, are very much site-specific and should be addressed on a case-to-case basis."

Bill offers his thoughts on the three key influencers:

BUILDING HEIGHT

Taller buildings generate greater concerns with respect to wind comfort and safety at grade-level. As winds attack a building façade, they are forced to flow down, over and around the building. This results in zones of high speed 'downwash' at street-level and the potential for reduced pedestrian comfort and safety. Low-to-midrise buildings typically do not suffer from strong downwash issues to such an extent, but can in certain instances. Suitable wind and thermal comfort conditions for patient terraces, healing gardens, and other outdoor areas can increasingly be more difficult to achieve as building height increases.



Winds incident on the face of a tall building are forced to flow over, around and down. This results in zones of accelerated flows and high wind speeds that can impact pedestrian comfort and safety at ground level.

Another key consideration related to building height is the stack effect. In tall buildings, as the temperature drops in the winter, the heat inside is turned up. That war m air wants to rise through the building, to find its way up and out. The warm air is less dense, it's buoyant, while the outside air is cold and denser, and wants to find a way inside. That upward drive creates suction on the lower floors. If you open an exterior doorway on a lower floor level, cold outside air comes rushing in due to a negative pressure on the inside and a positive pressure on the outside. The outdoor cold air will replace the warm air rising through the building and is intensified in taller buildings. This is known as the stack, or chimney, effect. The process is reversed in hot climates, but the implications for design are similar.

The stack effect can create a host of problems in healthcare environments including infiltration of odors, loss of containment and security, fire safety, mold migration and noise (whistling from airflow under doors etc.). Mitigation measures often include reducing the length of vertical air flow paths, such as sealing vertical mechanical (MEP) chases and incorporating a few doors in stairwell landings, as well as using vestibules, elevator lobbies, mechanically operated dampers and high strength seals on openings such as doors and windows to control, or create more resistance to, vertical air movement. Such measures have proven effective in traditional commercial and mixed-use settings. In healthcare environments there are added complexities surrounding IPC, and although the design community currently has solutions for some aspects, there is limited data to guide the design of high-rise healthcare environments. This is an identified area for future research.

A third key issue related to building height is the potential for falling ice and snow in colder climes. Ice and snow accumulated on exterior cladding elements and certain architectural features can suddenly release producing significant safety concerns. Sun shades and other unique features should be reviewed by a falling ice and snow specialist to establish risk and appropriate mitigation.

URBAN ENVIRONMENT

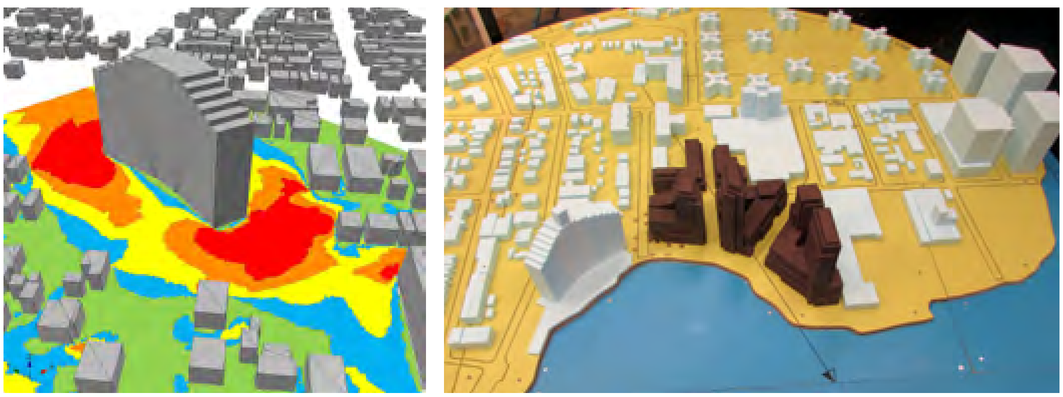
Healthcare facilities located in urban cores are typically surrounded by taller buildings that cast shadows. At higher elevations and other areas of increased wind activity, the presence of shadows can enhance cooling of outdoor spaces. These effects are important to the design of outdoor healing and therapy spaces, where thermal comfort plays a key role in functionality. If an outdoor healing space is too windy or frequently in shade, it may simply become too cold and unpleasant to use at all.

Elevated outdoor therapy spaces exposed to site winds can suffer from poor comfort conditions that affect function and safety. Thermal comfort, air quality, snow and ice accumulation can all be affected by the site microclimate. Mitigation strategies include orientation, location and size of sheltering and screening strategies involving landscaping and balustrades.

An evaluation of wind and thermal comfort for these areas is useful for establishing controls such as space orientation and screening. Through some simple but effective design measures, wind and thermal comfort conditions can be steered to arrive at conditions that are conducive to rest and recovery. These control measures can have significant implications on the architectural design, and as such are best introduced during early planning when orientation and massing is being developed. Fine tuning often occurs later as the landscape design evolves, where an objective is to extend the usability of these critical healing spaces well into the shoulder seasons.

CONDENSED FOOTPRINT

A condensed footprint will limit the locations of points of egress and the ability to shelter these points from the effects of accelerated wind flows. Difficulty with operation of doors, snow drifting and overall comfort and safety are key concerns in these areas. Additionally, outdoor amenity and therapy spaces located on upper floors are susceptible to increased wind exposure and the issues discussed previous



Analysis of microclimate effects involves one or a combination of expert reviews, computational modelling and wind tunnel testing of scale models of the development. The choice of study depends on the complexity of the site and building form, and the information required from the study.

Summary

In this paper we have addressed some of the critical environmental factors that must be considered in the design of high-rise healthcare environments, these include:

Air quality — the provision of fresh air in and around the building;
Acoustics — occupant privacy and freedom from noise disturbance;
Vibration — functional diagnostic equipment and procedure spaces; and,
Wind and climate — comfort and safety in outdoor spaces and stack effect inside.

Each of these factors has a direct impact on the quality of healthcare delivery and their significance during design is determined by the three key influencers:

The building height — exposure to environmental effects at upper elevations;
The urban environment — building site and density; and,
The condensed footprint — challenges with layouts and stacking.

The roles of these influences on a project are site-specific, and must be managed holistically to effectively address the often competing requirements that arise among the various environmental issues.

Beyond the constraints that high-rise environments introduce related to environmental effects, are some unique opportunities. We conclude with some thoughts on a couple of these:

Natural ventilation and patient windows — the use of operable windows in hospitals has long been a controversial topic due to the impacts on safety, IPC and related issues. These impacts are weighed against the benefits of access to fresh air and the possibilities for natural ventilation due to building height and microclimate influences (i.e., stack effect and exposure to wind activity at upper elevations). A successful design must consider wind interaction with the building form and exhaust sources, as well as issues such as noise ingress if operable patient windows are to be considered and how to control stack effect in an open patient door environment.

Unique therapy spaces — the benefits of outdoor gardens and therapy spaces on healing are well known. In tall building environments, these outdoor spaces can offer unique vistas and the opportunity to harness the microclimate for therapeutic use. Wind and music therapy may be two such opportunities. Harvesting the wind to produce the illusion of a motorcycle or bicycle ride through kinetic sculptures comes to mind. The Aeolian harp and other aeroacoustic devices, which produce sound as they interact with wind, could be employed for use in music therapy.

The emergence of Biophilic Design, which seeks to improve the connection between people and nature, offers new opportunities for creation of outdoor healthcare spaces. In order for these spaces to function as intended, a harmonization is necessary between the built and natural environment, which addresses many of the issues outlined here. Fresh air, freedom from noise intrusion, and thermal comfort will be key elements to consider as these spaces evolve.

These are exciting times for healthcare, and as the industry evolves amidst advances in materials, technologies and treatments, we look forward to the many challenges and opportunities that they bring for the design community.

[1] A summary of the issues presented at the CCHRB seminar, among others, can be found in Douglas King's CTBUH paper "Challenges and Opportunities in Vertical Healthcare Design", available for download — click here.

[2] A current list of the world's tallest hospitals can be found in the Issue II of the 2016 CTBUH Journal, available for download — click here.