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Past, Present, and Future: Building Sustainable Mega Skyscrapers

As part of everyday life our society inhabits buildings. People have an inherent need for functional spaces because we as a society are always moving forward, innovating, and seeking to improve our way of life. Buildings serve the purpose of providing a warm home to raise a family, an office to conduct business, a hospital to care for the sick, and for higher education institutions to teach knowledge. Looking back on history thousands of years ago, the early builders accomplished amazing feats for their time: The Egyptians built the great pyramids and the Romans became the world's most powerful empire by building aqueducts and stone roads to support their massive city and population. As increasing knowledge of construction practices flourished, so did the colossal accomplishments of man. With each marvel of engineering finished the architectural bar became higher and higher. Buildings became wonderful yet mysterious creations to gaze upon. When I see a skyscraper I think of them as beautiful enigmas encased in steel and concrete. Their beauty stems from never knowing what to expect. On the building's façade there is a certain architectural look. But on inside the structural system (call it the skeleton of the building that is not meant to be seen) can look vastly different and profoundly intriguing. Whenever you think you've seen all there is, you are stunned by another architectural creation that you did not think was possible.

Introduction

Population growth, economic prosperity and demand for functional spaces to inhabit has created one of the most exciting periods to witness the rise of mega tall skyscrapers throughout the world. Countries, architects, and corporations from all over the world are designing and constructing the tallest and most awe-inspiring buildings. In a relatively short span of time over the last 50 years there has been an exponential growth in the size and scale of constructed buildings. Not only are buildings rising to monumental heights never before thought possible, they are being constructed in much short spans of time due to advances in computer technology and they are becoming more structurally stable because of research in building materials. Architect and engineers alike are constantly exceeding the boundaries of what people think can be accomplished. Present day skyscrapers rise thousands of feet in the sky and can withstand massive earthquakes and wind forces. As our society become more technologically sophisticated, a need has developed for the buildings to take advantage of new technology. The feats of engineering that are being envisioned are simply amazing, but most important are the projects that mature from vision to creation. We have learned and observed over the years that our concrete and steel artworks need to be less harmful to the surrounding world. Our understanding of the negative impact we have on the environment has become much more transparent. Skyscrapers will one day be intelligent, self-sustaining masterpieces that positively benefit the environment, rather than destroy it.

The Evolution From Master Builder to Architect/Engineer/Contractor



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Figure 1. Basilica di Santa Maria del Fiore

For centuries during the Roman Empire and Italian Renaissance the greatest engineering achievements were designed and built without an architect. During these periods the architecture profession had not yet been established. The

designer and builder was a single

entity known as the “master builder”. The Pantheon and Colosseum in Rome, Italy and the Basilica di Santa Maria del Fiore in Florence, Italy (known as “Duomo,” or dome in Italian, see Figure 1 below) are examples of structures that did not have an architect, instead they were managed by a master builder. As projects became more sophisticated and complex a need arose for specialized professions within building. The architect, engineer, and contractor roles began to emerge. During the early 20th century the divide between the architect and builder widened. A single person was no longer responsible for an entire project, now architects focused on the design and contractors specialized in construction; there was no longer an overlap in responsibilities. Today, architects and engineers are highly specialized professionals. The architect determines the layout and function of the building, the engineer ensures there is zero possibility of structurally failure, and a contractor provides the materials and labor to completely and accurately construct the building. For modern building construction in the 21st century this

has been the project delivery method. However, a better collaborative and integrative practice is being more widely used to build the mega projects of the future.

The separation between designer and builder has caused a collaboration disconnect between the architect providing a highly function space, but also a place that is practical to build. Traditional “Design-Bid-Build” project method, where the architect drafts the plans independently, and a contractor places a bid to build the job is increasingly becoming less appealing than the developing idea of Integrated Project Delivery (IPD). IPD is a collaboration between the architect, engineer, and contractor during the first design phase. All parties work together to propose a plan that takes into account the issues of functionality, aesthetics, and constructability. The architect and contractor form a joint-venture and work as one unit. In essence, the building industry is making its way back to the idea of a master builder. Rather than a separation between design and construction, the architect and builder form a team that work together. The trend of using Integrated Project Delivery on projects allows for shorter overall construction duration, more structurally sound buildings, and exterior facades that are more appealing to dwellers. IPD has more advantages than traditional “design-bid-build” delivery because it takes into account emerging technology to complete the project in a short amount of time, more accurately, and with high level of quality.

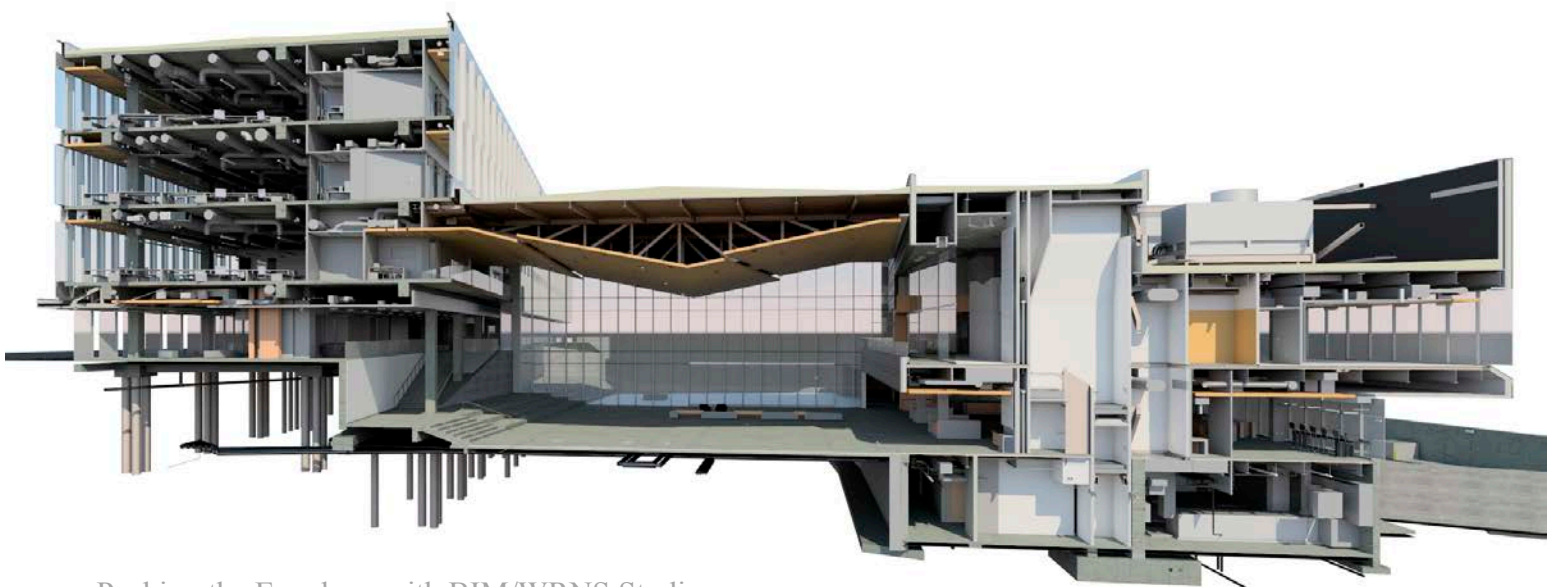
Building Information Modeling (BIM): A Catalyst For the Construction Industry to Embrace the Digital Age

For a moment let’s use the building-body metaphor and think of a building as a living and breathing organism. The mechanical, gas, and electrical pipes provide food intake to the building by supplying hot and cold water and energy to power outlets and interior lights. The brain and

nervous system of the building act as the control enter of electrical equipment that monitors security cameras, indoor air quality, room temperature, and energy consumption. The heating and ventilation system acts as lungs by supplying hot or cool air throughout the building. Lastly, the building foundation is similar to legs and feet because it supports the building from falling over [4]. Modern high rises, schools, and especially hospitals have a highly intricate layout for these important systems.

A project that does not take advantage of BIM can have thousands of conflicts between the various building systems. For example, the builder is planning to install the mechanical pipes, however the path interferes with the placement of the ventilation system. Both systems cannot be located in the same place, thus the architect must revise the finalized drawings and resolve the conflict by changing the layout of the two conflicting systems. During the revising process valuable time is lost, which can cause efficiency to drop and in turn lengthens the duration of the project. Fortunately, an important advancement known as Building Information Modeling has quickly revolutionized the industry.

The advancement of technology during the last decade has had a profound impact on the building and construction industry. Buildings can now be digitally modeled brick by brick, wall



Pushing the Envelope with BIM/WRNS Studio
Figure 2. Building Information Model Cross Section

by wall, before construction begins. The benefit of utilizing BIM modeling software, such as Autodesk Revit, has allowed architects and builder to collaborate on a much more sophisticated and in-depth level that was not possible before. All the building systems are now fully integrated into the computer model. The architect builds the model in one of the many different BIM software and incorporates all aspects of the building, from the water pipes, ventilation shafts, and electrical conduit. Conflicts that previously could only be recognized during construction now are identified and corrected before the project begins. This technique is known as “clash detection.” This is just one of the many helpful applications BIM has provided. BIM also improves construction quality, shortens total construction duration, and improves collaboration

between all professional parties involved. Building Information Modeling is an important aspect that has allowed super tall skyscrapers to be safely and efficiently built, despite the previous lack of coordination and collaboration.

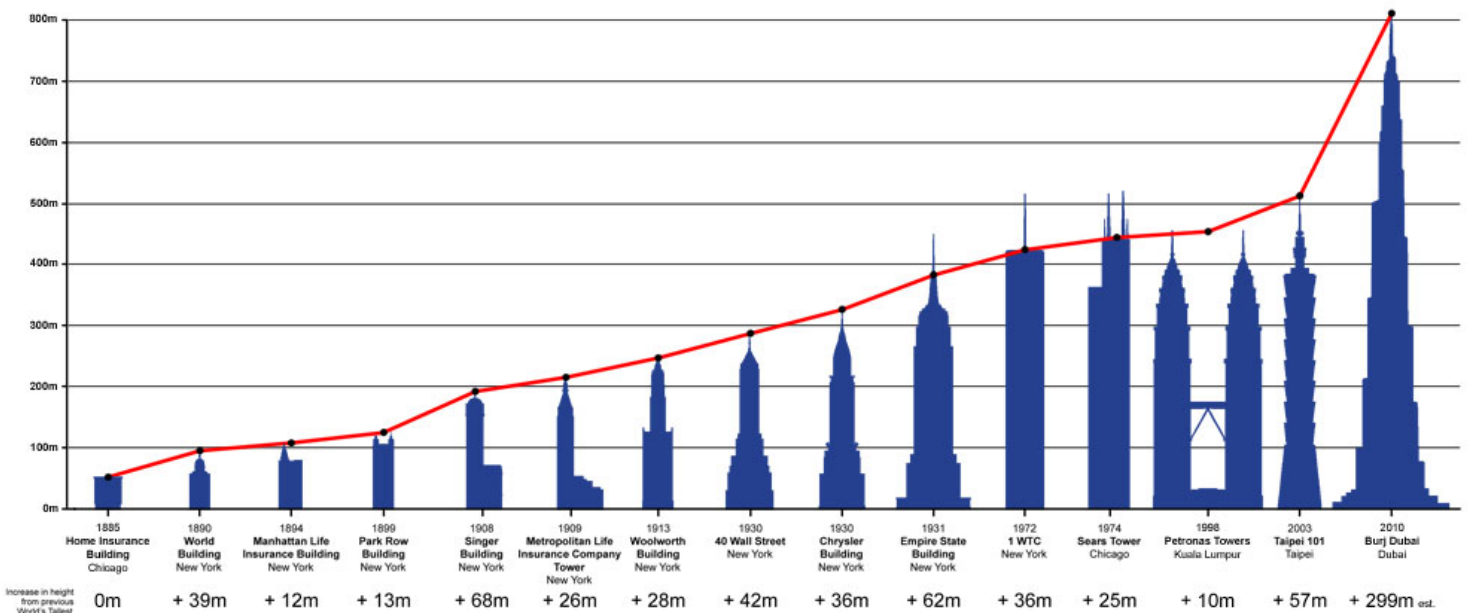
Pushing the Limits of What is Possible: When The Sky Isn't the Limit

The size and complexity of buildings being built or proposed today were previously inconceivable to imagine in the 19th century. The most iconic of these skyscrapers is the Empire State Building, which held the crown of tallest building in the world at 1,250ft (381m) for forty-one years from 1931 until



DonalDYtong/Wiki Commons
Figure 3. Burj Khalifa

1973 [5]. For decades it stood as a symbol of the astonishing engineering feats that man could accomplish. In the last forty years the height and scale of skyscrapers has nearly doubled and continues to rise. As can be seen in Figure 4, the height of the tallest building in the world has been sharply increasing. In Figure 5, the list of 20 tallest buildings in the world by 2020 has eight skyscrapers that are classified as mega tall and exceed 1967ft (600m). The current tallest building in the world is the Burj Khalifa (see Figure 3 Above) in Dubai, United Arab Emirates. Completed in 2010, the Burj Khalifa stands at 2,717ft (828m) high, has 163 occupied floors, and cost \$1.5 billion (USD) to construct [6]. Though a building of this height and magnitude was an endeavor never before thought possible, the title of world tallest building is only held for a short period in this league of mega structures. The Kingdom Tower currently under construction in Jeddah, Saudi Arabia is set to dethrone the Burj Khalifa in 2019. At a height of 3,281ft (1,000 m) it will be by far the largest skyscraper in the world (see figure 5). However, it is only a matter of time before the limits are pushed even further and The Kingdom Tower is surpassed by an even more ambitious and astonishing structure.



Marshall Gerometta/Council on Tall Buildings and Urban Habitat

Figure 4. Diagram of all buildings that have at one time claimed the title of “World’s Tallest Building” as

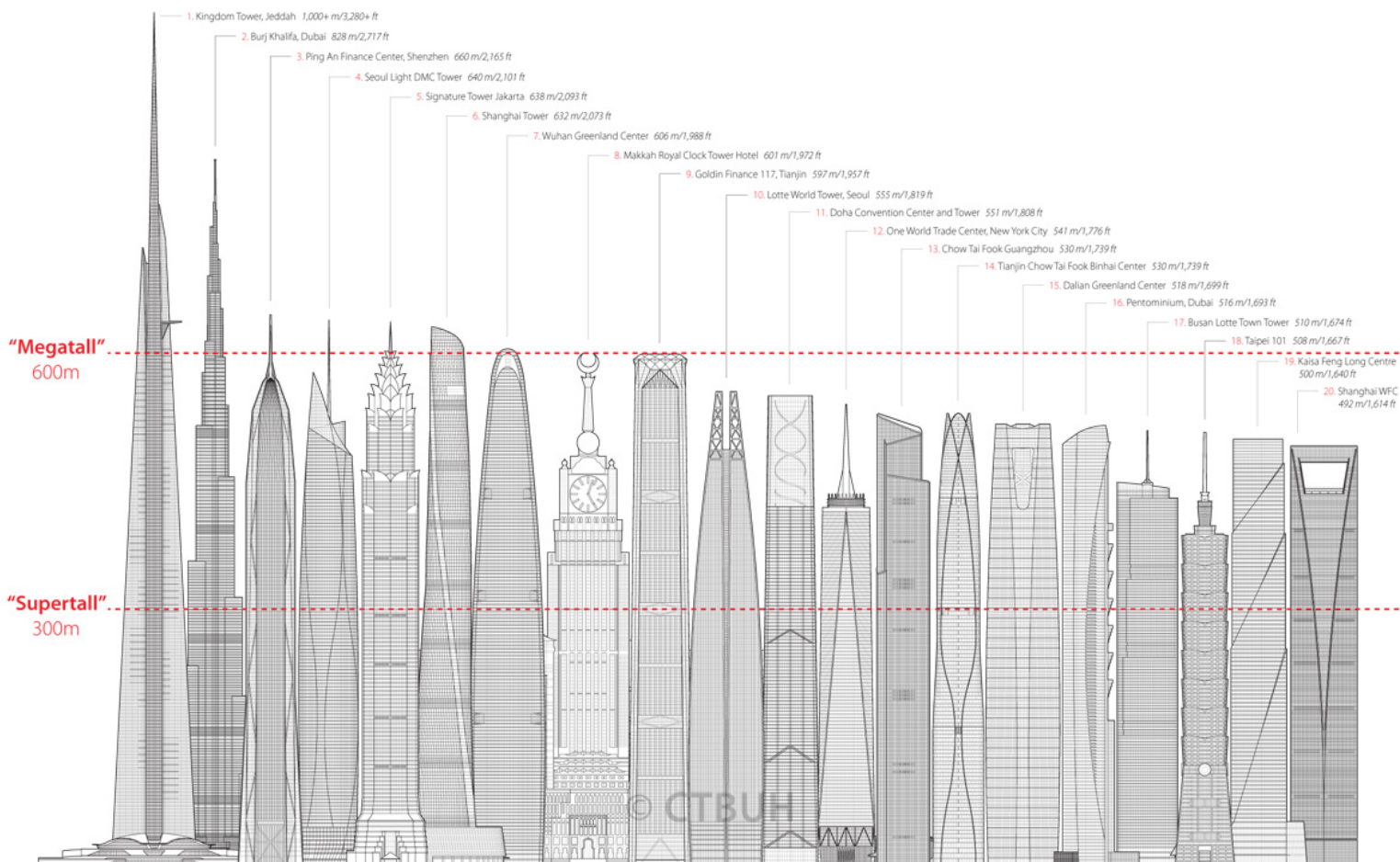


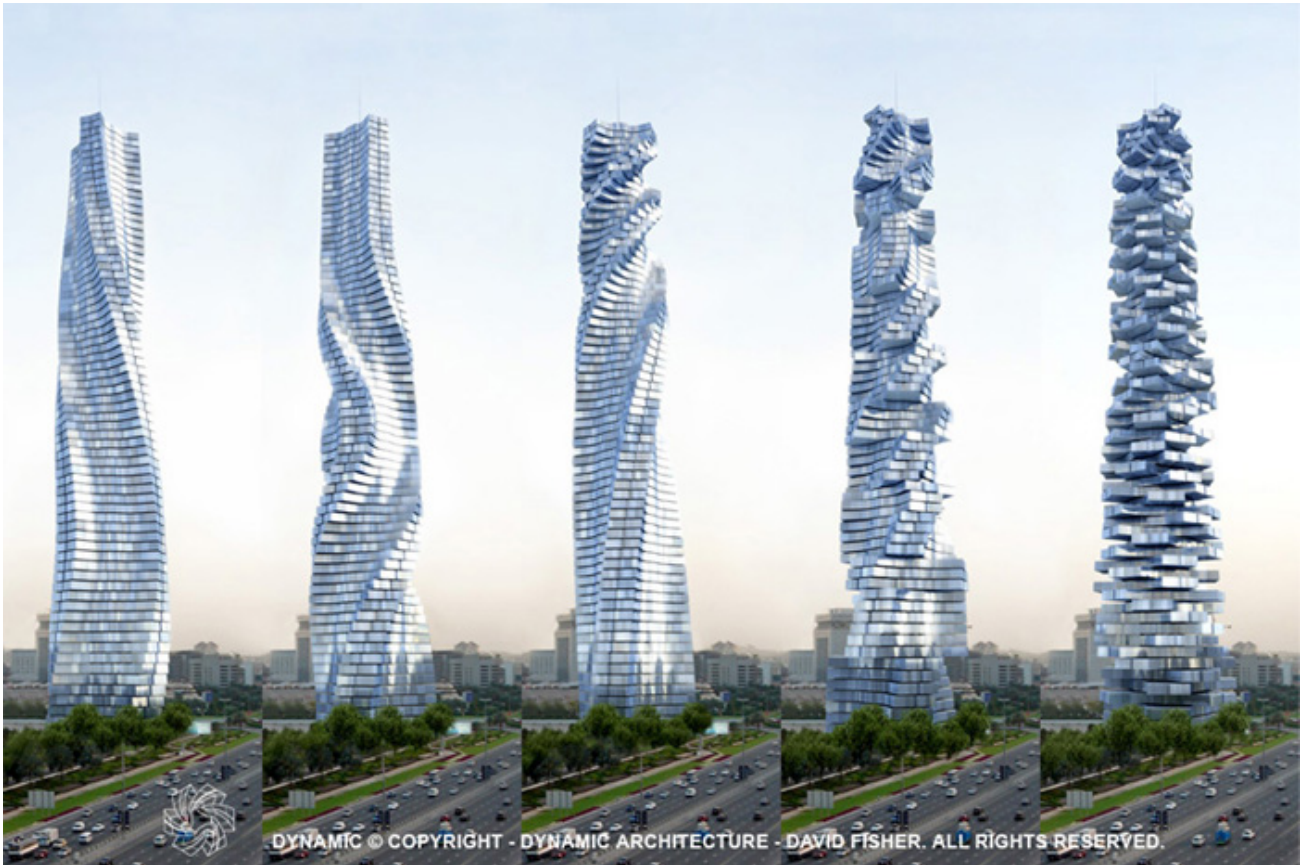
Diagram of the World's 20 Tallest in 2020 (estimated as of Dec 2011) © CTBUH

Council on Tall Buildings and Urban Habitat

Figure 5. Diagram of the predicted World's 20 Tallest in the year 2020 as of Dec 2011

How Rotating Buildings Could Inhabit Major Cities in the Future

The possibilities of what engineers and architects can dream up as a result of advanced understanding of building technologies has continuously pushed the limit of what is possible, or rather rotated the limit of what is possible. In 2009, a designer by the name of David Fisher, creator of Dynamic Architecture, proposed a 60-story rotating tower to be built in Dubai, UAE. Named the Dynamic Tower, each floor rotates independently at a rate of one rotation every 90 minutes [7], giving the wealthy occupant continuously changing 360 degree view of the Dubai skyline. This visionary building is possible due to the advancements in prefabricated construction.



David Fisher/Dynamic Architecture
Figure 6. Dynamic Tower, Dubai, UAE

Each floor is composed of forty individual modules that are assembled in a factory and all building systems, including kitchen and furniture, are preinstalled. The core of the building is a concrete shell that acts as an axis for the floors to rotate. Housed inside the concrete core are the elevators, electrical conduit, plumbing pipes, and 79 wind turbine that are the source of power for the floors to revolve. According to an interview the Wall Street Journal, David Fisher noted that the “Horizontal turbines, like airplane propellers sandwiched between the floors, will gather power from the wind” and even goes so far as to say “the building will actually produce more energy than it consumes” [8]. The exterior will be fitted with solar panels to provide power to the building. Not only is the Dynamic Tower a pioneer in prefabrications, it will have a low environmental impact and in some ways help the environment.

Despite this innovative and unique concept, the project ran into the issues of financial issues. The architect also received criticism because he is not well known in the architecture community nor has he ever designed a skyscraper before. Furthermore, the timing of his vision could not have been worse, as it came to light in wake of the 2009 global financial crisis. Currently, the tower is on hold indefinitely. Regardless of David Fisher's prior experience or reputation, this is a revolutionary concept that will become a reality in the future. The world disparately need architects that push the envelope, go beyond the boundaries of conventional thinking, and challenge the status quo. Mr. Fisher has jump started the revolution of moving buildings and I am excited for see them in the future.

Intelligent Buildings That Produce Energy, Rather than Consume It

When we look at ourselves as a species on earth, we are undoubtedly thriving and prospering unlike any other period in time or any other animal. People live longer, overcome deadly diseases, and have an improved the quality of life. In 2012 the world population reached an astonishing 7 billion. By 2050 it is predict that the population of the world will reach 9 billion [1], and an estimated 7 of 10 people will live in cities [2]. The current infrastructure and resources in the United States and countries abroad are not equipped to sustain an ever-increasing population. From estimates, nearly 70% of the world's population will live in cities by 2050. It is imperative now more than ever to set a high standard for self sustaining buildings and structures. Organizations such as Leadership in Energy and Environment Design (LEED) and the Living Building Challenge have helped us step in the right direction. However, it is only the first step. As a society we need to take more impactful steps to ensure that our cities are not overcome with pollution, overpopulation, traffic congestion, and crime. It is important to look to the future

so we can begin plotting a course to buildings that positively benefit the environment, rather than harm it.

A study conducted by Arup's Foresight + Innovation Team took an in-depth look on how buildings will function and adapt to support our needs as a society in the next thirty years. The future of green technology will be smart buildings that are equipped internal and external sensors to fully monitor all aspect of the building's performance and surrounding environment. In order to take this step buildings will need to become fully integrated into the surrounding community, manipulate the environment to the benefit of the dwellers, and enhances the lives of daily occupant. Essentially, we need to design smart buildings systems that have the ability to identify, adapt, and change so they are environmentally efficient as possible. A system of smart grids that connects the building to the city's infrastructure and to other building will be used to effectively monitor all aspect of the building, from energy consumption, water usage, and air quality. To clarify, smart grids monitor the entire building, the activity of the occupants, as well as the environment to provide the most effective energy usage.

In the report, "It's Alive! Can You Imagine the Urban Building of the Future" a rendering of a living building in 2050 is featured. The key aspects of this buildings is its ability to monitor and adapt to the inhabitants and the environment, prefabricated modules have the ability to be upgraded or replaced to fit the need of the community, such as a need for more living areas, restaurants, schools, or hospitals. Robotics will be integrated into the smart system to help with maintenance and rearranging of modules. Additionally, the smart building's concrete structure will have the ability to self-heal cracks that develop over time. Structurally, a small crack in a concrete slab can lead to deadly structural failure due to the weakening of the overall concrete shell. Scientist are developing a protective coating that is activated by sunlight to self-heal

cracks. According to researchers a coating that contains polymers and microcapsules will active once exposed to sunlight and heal the cracked concrete [9], ensuring a long and sustained life cycle for the concrete structure.

The building of the future will be able to generate and sustain resources. These structures will take full advantage of capturing energy through photovoltaic cells on the exterior. Photovoltaic technology will be synthesized into paint and directly applied to the exterior surface of the building. Now the entire façade can be utilized to capture sunlight. The exterior structure will also use wind turbines to harness energy from the environment and produce drinking water from humid air [1]. Similar to photosynthesis in a plant, buildings will be equipped with an exterior filter membrane that take up the space of an entire floor at mid to higher levels of the structure and collect harmful carbon dioxide from air and convert it into oxygen, thereby improving the quality inside and around the building. Heat recovery windows will be installed where windows are required. The windows use natural ventilation to lessen the amount of heat that is loss, thus saving energy costs. Lastly, buildings will be fully integrated into the transportation system of the city. There will be underground high speed subways directly linking to the building occupants to the city. At ground level there will be bike rental stations and ride-sharing programs to encourage dwellers to take advantage of sustainable transportation.

Conclusion

Without a doubt the engineering marvels that the human race has accomplished within the last several hundred years is simply extraordinary. Our society has truly become masters of the transforming raw material into skyscrapers that extend beyond the clouds. With this in mind it is important to note that with all the resources and knowledge we have about the present and

future of building, it is nearly impossible to predict just how tall buildings can get or if buildings will truly become 100% sustainable. If there is one key take away from this article it is that architect and engineers will not disappoint with their architectural creations. It's entirely possible that one day buildings will grow from seeds like tree and the times when people labored over their construction will be a thing of the past. What we perceive to be impossible currently could just be created in the not too distant future. Builders in the early 19th century thought buildings could never exceed past ten stories. Yet that number has been passed by twenty fold. Humans are always pushing the limits of what can and will be done. Personally, it will without a doubt be exciting to see what masterpieces that will sprout out of the ground by 2050.

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About this Article

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Michael Soh is a senior studying Civil Engineering (Building Science) at the University of Southern California. His inspiration for this article is from his passion for buildings. Upon graduation Michael plans to work with for a large construction contractor in New York City building high rises.