Megastructures: Past, Present, and Future

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During the '60s, theorists and architects such as Yona Friedman proposed visions for megastructures where residents could freely come and build their units with individual variations. However, there were no technological means to build such structures, and these visions appeared to be unrealistic at the time. This paper discusses how those visions could be re-envisioned through the use of anticipated new technologies and speculates about possible structures and their impacts on our living.

Keywords: *Metabolism, modular systems, space elevators*

1. BACKGROUND

Since more than half a century ago, architects and theorists such as Yona Friedman have proposed ideas for mobile architecture such that the inhabitant should be the sole conceiver of his own living premises within a structure that would allow individual variations (Friedman 2016).

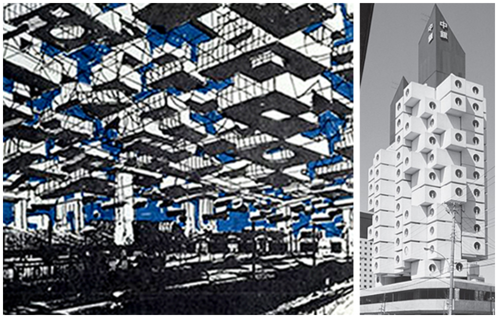

Figure 1
The Spatial City by Yona Friedman, 1959 (left) and Nakagin capsule tower by Kurokawa, Tokyo, 1971 (right).

Friedman sketched floating space-frame-like superstructures over existing cities that provide flexibility for inhabitants to construct their dwellings freely while maintaining physical integrity of the community. His vision appeared to be unrealistic, as there were no technological means for suspension of such structures or transportation of individual dwelling units (Figure 1). During the '60s, megastructures with pluggable prefabricated pods on the infrastructural core, proposed by Japanese Metabolists such as Kisho Kurokawa (Figure 1), had a practical limitation due to their need for transportability for reconfiguration and the obsolescence of their infrastructural systems for adaptation (Yatsuka and Yoshimatsu 1997).

However, anticipated new technologies for the 21st century-hyper-strength materials such as carbon nanotubes; space elevators, wireless communications, and energy transfer; autonomous drones and artificial intelligence-could realize a transformative vision for a new kind of living for future generations. The paper introduces possible ideas for speculative structures for living supported by anticipated new technologies and discusses how new possibilities for visualization and validation can help us envision such structures that have yet to exist.

2. EMERGING TECHNOLOGIES

Following in the footsteps of these predecessors, this paper introduces some possible visions for flexible

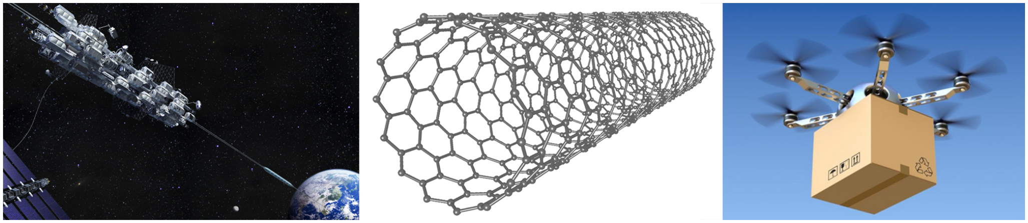

Figure 2
Obayashi Corporation's space elevator (Ishikawa 2016) (left), Carbon nanotube (middle), Amazon's drone delivery [1] (right).

habitable structures that can be constructed using innovative technologies and ideas that had yet to be fully introduced in their times. Some theoretical physicists foresee that the invention and realization of a space elevator could provide gravity-free spatial structures supported by the balance between the centrifugal force and gravity of the earth and connected through space elevators. The introduced visions will be based on the premise that high-strength lightweight materials such as carbon nanotubes will become available for manufacturing the required length of a space elevator (Figure 3). In theory, such a gravity-free structure, with auxiliary uplift support from helium-based high-altitude solar platforms, would establish a second "ground" for future residents of Earth without harming natural and artificial resources on the existing ground (Figure 3).

In fact, the Japanese general construction company Obayashi Corporation has announced that they will have a space elevator constructed by 2050 due to the advances in carbon nanotubes (Ishikawa 2016), and witnessing such structures might not be too far away from our time. The elevator will reach 96,000km into space and will transport people and cargo to a new space station. Unlike in the era of the Metabolists in the '60s, transfer of resources, including energy, can be done wirelessly using the conductivity of carbon nanotubes or laser power beaming, which reduces the heavy reliance on infrastructures that has been preventing faster updating of systems. Metabolists did not modularize mechanical, electrical, and plumbing systems for their infrastructural cores, unlike the way they did for their replaceable housing units. The cores that structurally and mechanically support housing units were not replaceable and updatable. Thus, the life spans of their buildings became shorter than expected. Luna Ring, proposed by Shimizu Corporation, has demonstrated schematic ideas for power generation using a ring of solar cells around the moon and transmission of the power using microwave laser beams to earth (Shimizu 2009). In terms of innovations on mobility, the SkyPod project by PLP Architecture has demonstrated an innovative idea to externalize and free up vertical transportation for ultra-tall buildings (Hesselgren et al. 2018), and some companies, including Uber, are developing drones that can be used for daily transportation. These proposals by professional practitioners in recent years indicate that those ideas that were once regarded as sci-fi stories have become feasible for planning. The paper further speculates about what is possible based on speculative yet thoroughly scientific (not sci-fi) studies.

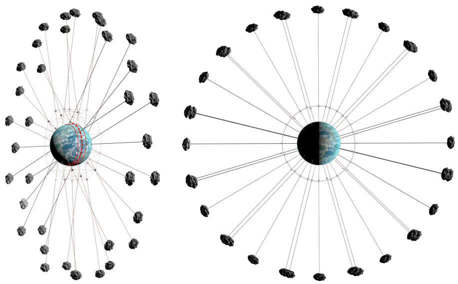

Figure 3
Space elevators constructed repeatedly around the equator at equal intervals inspired by Polyakov (1977) (diagrams not in scale)

3. PROPOSED STRUCTURES

This paper introduces speculative ideas for habitable modular pods that can be aggregated, rearranged, and disconnected based on each resident's needs, and that can be transported and reconfigured using advanced autonomous drones working as assemblers of the whole system (Figures 7). Inventions of hyper-strength materials could suspend portions of structures and allow them to use more lightweight materials for members only under tension. Thus, more dynamic reconfigurations of pods can be done.

Technical Details

As stated in the previous section, space elevators using carbon nanotubes could provide gravity-free spatial structures supported by the balance between the centrifugal force and gravity of the earth. In theory, these structures can be constructed repeatedly around the equator at equal intervals (Polyakov 1977). It is also known that the location of these base stations could be offset from the equator up to 35-degree latitude in north and south, which could allow us to construct arrays of space elevators in several loops around the earth, braced diagonally, forming further stable 3-D structures (Figure 3). The current estimated payload for such a space elevator is roughly 20 tons each (Edwards and Ragan 2006) (Beletsky and Levin 1993) and, with additional uplift from helium-based high-altitude solar platforms, in principle, it is possible to suspend lightweight habitable modules on such structures (Figure 4).

Such above-ground structures could provide additional areas for possible habitations and harvesting of resources without harming natural and artificial resources on the existing ground. As some theorists in the 60's such as Friedman suggested, floating structures could be a way to respond to issues such as the exponential increase in populations and pollution in the future. The appropriate altitude for such structures' height location needs to be carefully considered based on the environmental conditions and the proximity to other key stations above and below the residents. Silica fiber tiles, an effective insulator that was used for the Space Shuttle's thermal protection

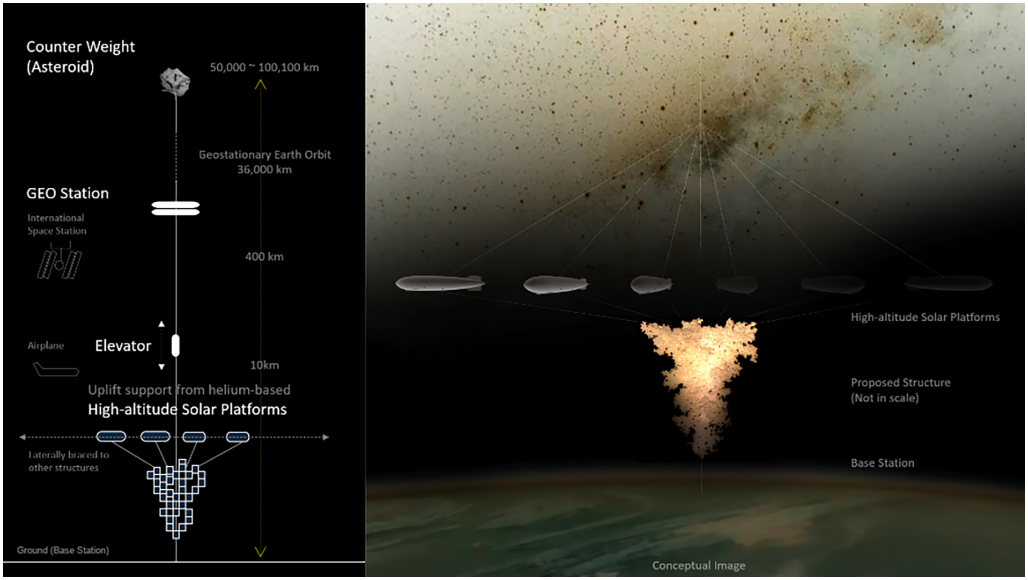

Figure 4
Proposed structures using a space elevator

Figure 5
Proposed structures using a space elevator and a reconfigurable module transported by a drone

system, could be used to tolerate anticipated acute temperature differences for living up in the air at different altitudes. They are indicated with rough textures in Figure 11 and prevent heat transfer.

The composite material using carbon nanotubes could be theoretically at least ten times stronger than steel and half the weight of aluminum if successfully manufactured and provides necessary properties for such lightweight structures. The paper proposes a 9m-cube module with approximately 180m^2 habitable space which can house one to two families. Each unit has six operable square openings at the middle of all six faces, and they can be connected through the operable mechanical joints that provide air-tight physical connections among adjacent units with sufficient structural strength. Modules can be attached to the space elevators' platforms and can form clusters by attaching themselves to each other and to suspension cables from the space elevators. Modules have internal 3-D corridors that internally connect residents and circulate physical resources such as fresh water and air using internal omnidirectional transportation cabs, while other non-physical resources such as communications and energy can be wirelessly transported-for example, using laser-power beaming technology (Shimizu 2009). Worth noting here is that there is no infrastructural core, unlike the Metabolists' buildings, and infrastructural functions are instead integrated inside the units, which allows for more variations for clusters' configurations.

Autonomous drones would allow us to live, work, and travel anywhere we like by functioning as transporters and assemblers of the habitable mobile units that can be nested to the floating structures (Figure 7). Tiltrotor drones with a crane and grippers, which are already near existing technologies, as seen from Amazon's drone delivery (Amazon.com, Inc. 2019) and Bell Nexus (Bell Helicopter Textron Inc. 2018), can move and plug our units into the best locations based on our preferences, proximity to elevator platforms, environmental factors such as solar radiation,

Figure 6
Possible ideas for speculative structures for living supported by anticipated new technologies.

structural stability, and so on. Each module can be an origami-like foldable structure made of hinged carbon nanotube composite panels covered by inflatable multi-layer Ethylene tetrafluoroethylene (ETFE) for further rapid reconfigurations for multiple units. A single drone can transport multiple modules to the site in a folded state and can unfold them on-site using its gripper and crane for the installation. ETFE is a lighter material for glazing than glass, robust, and a good insulator. Multiple drones can work collectively to transport larger clusters to realize faster reconfigurations (Figure 10).

Visualization and validation methods

Visualizing, validating, and communicating such speculative visions and ideas could be quite challenging and time-consuming if it required the use of multiple separate application platforms. However, the recent development of game engines such as Unity 3D and Unreal Engine using real-time shaders allows us to create and explore unbuilt and unseen speculative structures almost on the fly inside visually stunning immersive environments without requiring us to spend hours on rendering frame by frame. Such production platforms allow for quick iterations and reshaping of three-dimensional constructs and enable us to virtually walk through inside of them by becoming avatars. Component-based design, commonly practiced in game design, allows for procedural generation of structures composed of building blocks with certain behaviors, characteristics, and logic through custom scripts (Figure 8). For example, aggregations of modules by incoming inhabitants were visually assimilated using a Diffusion-Limited Aggregation (DLA) algorithm with custom cellular rules to provide enough open faces for each unit (for details on algorithms, see Narahara 2010). The structure's structural stability was studied computationally using custom codes in C# by the author to visually represent its deformation. Although it was not fully implemented inside a game engine, at the very schematic level, the stability of the structure could also be estimated using computational physics features inside game engines with custom scripts.

Figure 7
A reconfigurable module transported by a drone

5. CONCLUDING REMARKS

The author wanted to illustrate a possible vision where the architecture could be built based on decisions by multiple individuals. As the pattern language shows (Alexander et al. 1977), having commonly identifiable and sharable design elements is an approach often practiced by researchers in order to ease collective design activities by multiple participants. In this proposed vision, the modular unit with identical joints has become a common interface to connect to neighbors. This conceptual vision may appear to be too systematic and dull for some readers. However, the system can have multiple types of modules with different functionalities and visual variations. Also, by connecting multiple modules, we can introduce functionalities beyond what a single module can serve for, for example, larger footprints for connected modules can provide communal spaces such as multi-purpose halls, conference rooms, and roof gardens.

In a society with the anticipated technologies, we are not bound to a specific location for living anymore, and there is no fixed resulting form for the proposed clustering structures. The autonomous drones can transport our living spaces anywhere while maintaining necessary virtual connections to conduct business tasks and various involvements with others in remote locations. The proposed structures' configurations can be constantly changed over time based on multiple individuals' collective decisions. In such

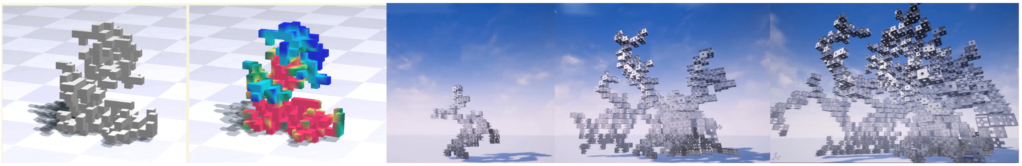

Figure 8
Procedural generations of structures (right), and Dynamic structural behaviors (left).

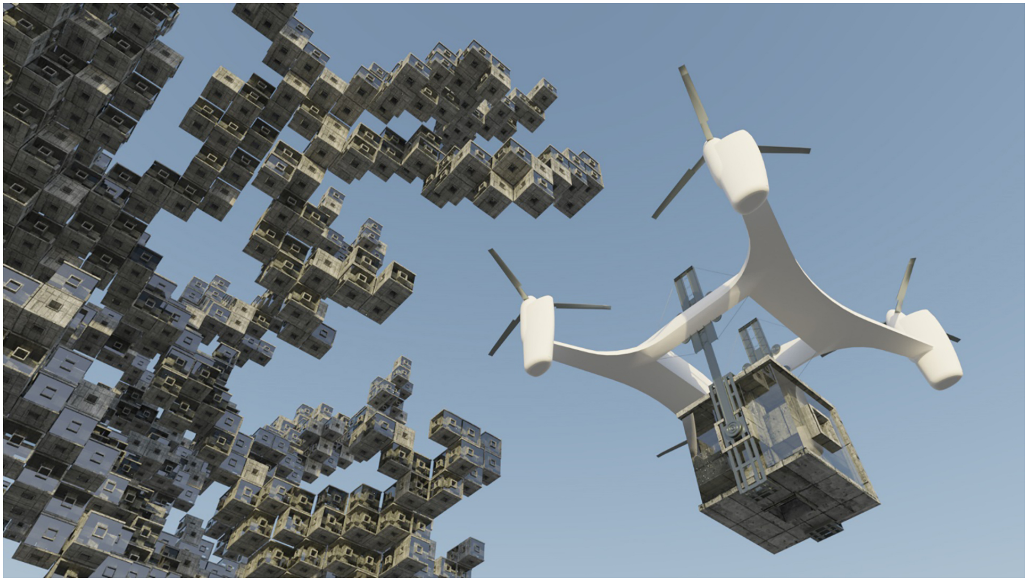

Figure 9
Reconfigurable modules transported by a drone.

hypothetical circumstances, we will develop and acquire very different lifestyles, values, ethics, and social structures. It might take many years to witness those changes. However, as a designer and architect, the author's intention was to take a small yet positive step toward these society-changing technologies by investigating feasibilities of such hypothetical structures based on speculative scientific (yet not sci-fi) studies.

Through the reinterpretation of utopian visions offered by theorists in the 60's, what we expect to see as architecture in the near future could be something much more indeterminate in terms of a physical form - formless and ephemeral with the possible use of anticipated technology. We could be virtually extremely closely connected with each other using the expected advances in digital communication technologies with a high level of augmentations for reality. Yet, using anticipated materials and engineering technologies, we could be simultaneously physically far apart and extremely differentiated from each other compared to the current standard. In a society where everything in the current physical world could be simulated and experienced virtually (including all human senses, possibly using brain-machine interfaces), what we expect to prioritize to have as an experience in the physical real world will depend on future residents of the earth beyond our imagina-

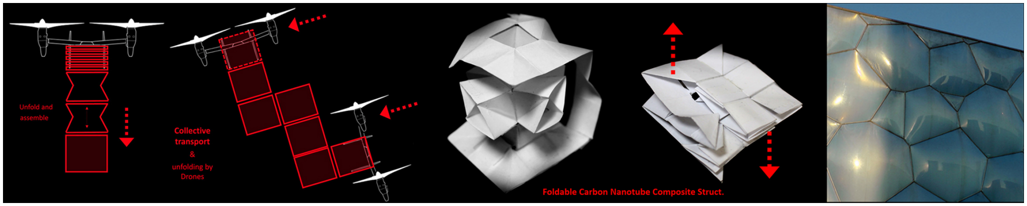

Figure 10
Transport & unfolding by drones (left), an origami-like foldable structure covered by inflatable multi-layer ETFE (right)

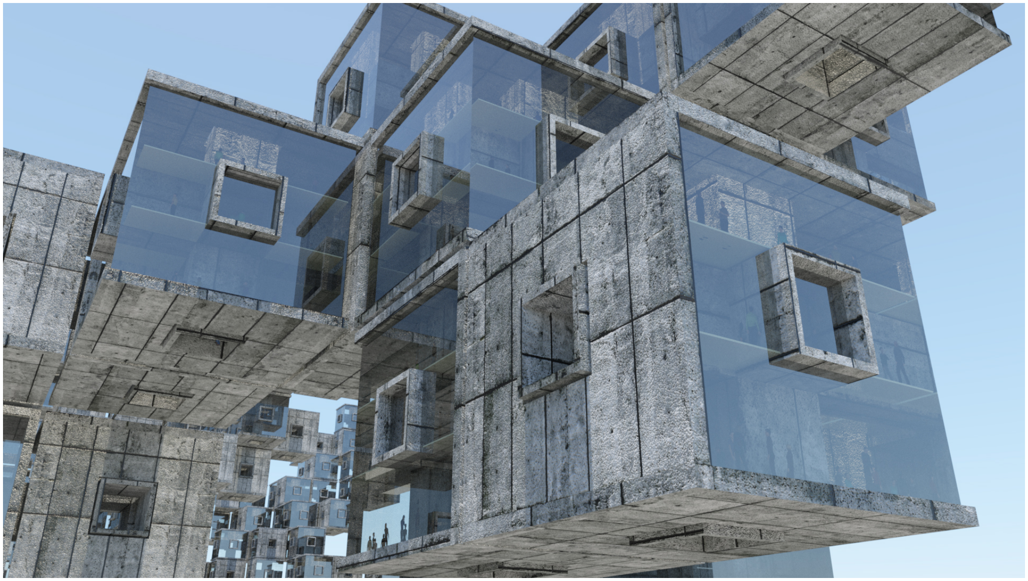

Figure 11
A view of the housing modules. Silica fiber tiles, an effective insulator indicated with rough textures.

tion. Conceptual visions created by our predecessors could be realized in unimaginable ways in a distant future, and they could be very different from the originally proposed vision. The author believes that the advances in and widespread use of visualization and validation tools will trigger an exponential increase in our creativity in the virtual domain, resulting in the realization of our physical constructs faster than ever.

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