Flexibility of the Dynamic Tower and Bacterial Flagellum

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Flexibility in Structure of the Dynamic Tower and Bacterial Flagellum

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Rule to Build by:

The “Rule to Build by” that both a bacterial flagellum and the Dynamic Tower follows is "to maximize flexibility of architectural form, assemble complex structures from simple repeating units." (Morris & Staudinger, 2016)

What:

The manmade structure is the Dynamic Tower by David Fischer and the biological structure that is being compared is the bacterial flagellum. Both consist of repeating subunits to form a final complex structure that move in circular motions that maximize flexibility.

How:

The Dynamic Tower is a proposed structure by architect David Fischer, whose vision is to construct a work of architecture that adjusts itself to life and thus, as a part of nature. Inspired by the Suite Vollard in Brazil, the world’s first rotating building, David Fischer planned to build an 80-floor tower, with each floor prefabricated on ground level and designed to rotate 6 metres per minute (Randl, 2008). These individual floor rotations give the appearance of a wave that runs vertically along the building. The core of the tower would be built at the construction site, serving both people and cars in elevators. This slim core would have to be strong enough to support all subunits and floors (Dynamic Architecture, n.d.). Each floor is composed of 12 subunits and will be assembled at the construction site via a lift system. As a result of the separation of each floor, each floor will be allowed to move individual with the wind, as the building is powered by horizontal wind turbine, one between each floor. Each wind turbine will produce 0.3 megawatts of electricity, which is said to be enough energy produced for 50 families according to the Dynamic Architecture website. Since solar panels will also be included in the construction of the building, this means that the two energy efficient sources combined could provide Dubai with $7 million USD worth of surplus energy per year (Dynamic Architecture, n.d.)

A bacterial flagellum is the filament or filaments that project out of a bacterial cell body, its main function being to help the bacterial cell to move in the desired direction. There are several types of bacterial flagellar arrangement schemes, which includes the following: Monotrichous, which have a single flagellum, Lophotrichous, which have multiple flagella
which stem from the same location, Amphitrichous, which have a single flagellum on polar ends, and Peritrichous, which have multiple flagella located all around the membrane (see Figure 4) (Titz et al., 2006). The arrangements of each flagellum maximize the bacteria’s movement potential.

Similar in form to the Dynamic tower, a bacterial flagellum is composed of subunits to increase flexibility and movement. These subunits are that of flagellin protein, a globular protein that arranges itself in a hollow cylinder, which is about 20 nanometers thick, forming the flagellum’s helical structure (see Figure 5). There is a “hook” adjacent to the outer membrane, allowing the axis of helix to point away from the cell to propagate motion. The end of the filament is composed of a capping protein (Diószeghy et al., 2004). The base of the flagellum that is connected to the cell body is called a “hook,” as shown in Figure 5, which connects the filament to the motor control centre of the flagellum called the basal body which are made up of multiple basal body rings. Gram-positive bacteria, which have a thicker peptidoglycan layer, have two of these basal body rings with one in the peptidoglycan layer and one within the plasma membrane. Gram-negative bacteria, which have a much thinner peptidoglycan layer, actually have four basal body rings. Within the basal body, there exists a pair of proteins called Mot, which propagates the rotation of the filament—this is named the Mot complex and is powered by the flow of hydrogen proton gradients across the bacterial cellular membrane. (Macnab, 2013). FliG proteins will reverse the rotation of the flagella to provide torque in the opposite direction if need be via a slight change in positioning of the FliG protein itself (Lloyd et al., 1999). When the Mot complex is rotating the flagellum, the long filament will form a long pitch supercoil, allowing multiple flagella at once to gather into one large bundle of flagella. This allows for the bacteria to move in a straight line. In order for movement of the bacterial cell body to occur, flagella typically rotate counter-clockwise. To move in the opposite direction, a shorter supercoil is formed, disassembling the bundle and thus, the bacterium may move about randomly, otherwise known as “tumbling.” (Manson, 2010).

Why:

The Dynamic Tower follows the rule: “to maximise flexibility of architectural form, assemble complex structure from simple repeating units.” The genius of the Dynamic Tower is revealed through its overall time construction reduction and energy efficiency. Each individual floor will be constructed in 12 subunits to expedite the general construction process, reducing construction time by about one half and save a huge sum of money that would have been spent on labour. Every subunit of each floor, completed with all electrical necessities, plumbing, and air-conditioning, will be delivered up to complete the structure via a lift system, with each individual subunit would be assembled upon the core that is situated on a strong foundation. The advantage of preassembling and constructing the tower via a lift system lies in time efficiency
and worker safety. The architecture is quite literally flexible and it’s possible that an individual would never see the same building twice, as there can be so many variations of the structure (Dynamic Architecture, n.d.). The flexibility of the building will allow the building to move with the wind, ensuring a higher resistance to earthquakes. Although the tower will be expensive to build, summing up around 330 million USD to construct, the rotating feature of the tower may be worth the investment—The tower would be generating its own electricity from the enormous horizontal wind turbines stacked between each floor, making the building incredibly energy-efficient (Dynamic Architecture, n. d.).

A building does not necessarily need to have any other function besides to provide shelter for people. In the case of the Dynamic Tower, it is very possible that the architects of the building want the tower to rotate for the sake of aesthetics, as well as to impress the world with addition of another stunning piece of architecture that matches the rest of the dynamic Dubai skyline. Like most of the buildings in Dubai, the Dynamic Tower will be flashy and world record-breaking, following its predecessors, the Burj Khalifa and Burj Al Arab. The aesthetics of a building alone can be reason enough to pursue this type of project.

The primary purpose of any flagella, not simply bacterial flagella, is to propagate movement of the cell body and the evolution has made it so that the flagellum does so incredibly efficiently in various manners. Firstly, the proteins that build up the flagellum are consistently vibrating, so any added force will cause the flagellum to spin (Cooper, 1976), making the system more energy-efficient. Secondly, the flagellum’s individual proteins spiral around the structure and this results in the flagellum’s filament to move in a propeller like motion (Lee et al., 2010). Converting rotational motor torque into thrust is one of the most energy efficient ways to propel any object forward. Without application of torque, the structure filament is stable but as soon as torque is applied, the unit proteins begin to rearrange. As the torque travels along the filament, the proteins closer to the base begin rotating whilst others near the tip are at still at rest. Eventually, when enough torque has travelled to the end of the filament, the entire filament will begin its propeller like motion (Arkhipov et al., 2006) as shown in Figure 6.
Figures:

Figure 1. The left side of the image illustrates how the Dynamic Tower will be constructed and the right side of the image lists assembling process advantages over standard architecture assembly. The bottom of the image shows the timetable for the entire construction process. (Image provided by Dynamic Architecture’s website at dynamicarchitecture.net).
Figure 2. Slender core of the Dynamic tower—in this rendering, a single subunit of a floor is being added onto the core via a lift system. (Image provided by Dynamic Architecture’s website at dynamicarchitecture.net).

Figure 3. Artist’s rendering of the Dynamic Tower to be built in Dubai by 2020. As stated previously, each individual floor rotates independently to form a wave-like pattern. (Image provided by Dynamic Architecture at dynamicarchitecture.net).
Figure 4. Examples of bacterial flagella arrangement schemes. A-Monotrichous; B-Amphitrichous; C-Lophotrichous; D-Peritrichous. Different species of bacteria have different numbers and arrangements of flagella. (Image provided by http://classes.midlandstech.edu.)
Figure 5. This image shows the basic structure of a bacterial flagellum. The three basic components are the filament, the hook, and the motor, which is a transmembrane protein embedded into the plasma membrane and cell wall. (Image provided by Pearson Education, 2011 at http://proteopedia.org/wiki/index.php/Flagella,_bacterial).

Figure 6. Illustrates the rearranging of the unit proteins, resulting in the propeller like motion of the filament. (Image taken from the Beckman Institute at the University of Illinois at Urbana-Champaign at http://www.ks.uiuc.edu/research/flagellum/).
Reference:


Pearson Education image from http://www.textbookofbacteriology.net/structure_2.html (n.d.).