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Tall Buildings + Skybridges + Envelope + Green = Greenplex: A Sustainable Urban Paradigm for the 21st Century

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Biography

Richard Balling is a professor in the Department of Civil and Environmental Engineering at Brigham Young University in the USA. He received his Ph.D. from the University of California at Berkeley, USA in 1982. He is a licensed structural engineer in the state of Utah, USA. He has published over a hundred papers on structural and multidisciplinary optimization techniques, and has received multiple research grants from the National Science Foundation of the USA. Twice he has been a co-recipient of the American Society of Civil Engineers (ASCE) State of the Art Award for his participation in the development of monographs on structural optimization. He also was a co-developer of a commercial engineering optimization software package named OPTDES that has been used by hundreds of organizations worldwide. Each year for the past four years he has taken between 18 and 28 engineering students to China as part of a study abroad program titled "China Megastructures". The students study the design of remarkable bridges and buildings in China.

Abstract

The skyscraper/sprawl urban paradigm of the 20th century is deemed unsustainable because it is characterized by: excessive exposed surface area that wastes heating/cooling energy, limited escape routes, lack of protection from severe weather conditions, and ground level congestion. A new urban paradigm is proposed for the 21st century called the greenplex. The three elements of the greenplex paradigm are: 1) tall buildings connected with skybridges at multiple levels, 2) an envelope that is supported by the buildings themselves, and 3) green technologies that sustain the buildings. The advantages of this paradigm are discussed, and images are given. The differences between the greenplex envelope and the free-standing dome envelopes are made clear. Existing structures that approach the greenplex paradigm are mentioned. The potential for the greenplex paradigm to eliminate travel congestion in high density cities, to be sustained without drawing power, water, and fuel from the grid, and to reduce the amount of required structural material are explored. Optimization techniques for the design of greenplexes are also considered.

Keywords: Urban Paradigm Sustainability Envelope Skybridges Greenplex

20th Century Urban Paradigm

As cities developed during the 20th century throughout the world, the urban paradigm that emerged was characterized by skyscrapers and sprawl. If one adopts a broad definition of sustainability to include consideration of social, environmental, and economic impact (Savitz and Weber, 2006), it is clear that the skyscraper/sprawl paradigm is unsustainable for at least four reasons.

First, there is excessive exposed surface area among the buildings in this paradigm. The energy required for heating and cooling buildings is directly a function of exposed surface area. This is a serious environmental issue when one considers that 48% of energy consumption in the USA is attributed to buildings, while only 27% of energy consumption is attributed to all forms of transportation (Architecture, 2010). In the 20th century, cities were designed to maximize the view for offices, hotels, and residences. The result was a geometric topology that maximizes exposed surface area. Heat is transferred in and out of buildings by convection as air moves in and around individual buildings. With rising energy costs, increasing greenhouse gas emissions, and decreasing fossil fuel supplies, this paradigm is clearly unsustainable. Can a new paradigm be conceived that reduces exposed surface area while retaining the all-important view?

Second, tall slender skyscrapers have limited escape routes. This was tragically demonstrated on 9/11/2001 when the vertical escape routes in the World Trade Center were cut off, and thousands of people died. Limited escape routes have repeatedly contributed to deaths in skyscraper fires such as the recent high-rise fire in Shanghai in 2010. Not only are people prevented from escaping, but emergency responders are prevented from rescuing when limited routes are cut off.

Third, 20th century cities expose people to bad conditions as they travel between buildings. Such conditions include air pollution, wind, rain, heat waves, freezing temperatures, blizzards, hurricanes, typhoons, and dust storms. Many cities in the USA were paralyzed by massive blizzards this past winter as snow made streets impassable.

Fourth, horizontal movement in 20th century cities is limited to the ground level. This means that all large cities throughout the world suffer from ground level congestion. Think of the economic loss as millions of people are stuck in traffic jams and clogged streets. Ground level congestion is also unsafe as it leads to accidents between vehicles and between vehicles and pedestrians. Even though it is possible to see the face of someone in an adjacent skyscraper, a visit with that person face to face requires one to descend to the ground level, navigate through ground level congestion, and ascend from the ground level. This is very inefficient.

The Greenplex Paradigm for the 21st Century

What if we simply: 1) connect skyscrapers with skybridges at multiple levels, 2) enclose them in an envelope that is supported by the skyscrapers themselves, and 3) sustain them with green technologies. For lack of an existing term, let us call this paradigm the "greenplex". The exposed surface area of the greenplex is the exposed surface area of the envelope, which is far less than the cumulative surface area of all the individual skyscrapers inside the envelope. Researchers have recognized that skybridges provide multiple escape routes for occupants and multiple access routes for emergency responders (Wood, 2003). The envelope protects people from bad conditions as temperatures inside the envelope are held constant, and air quality is maintained. Finally, the skybridges provide for horizontal movement at multiple levels and thus reduce ground level congestion.

Let's consider the three elements of the greenplex in more detail, starting with the envelope. Enclosing cities within envelopes to protect them from bad conditions is certainly not a new idea. In 1949, Buckminster Fuller proposed enclosing communities in a geodesic dome. Such a dome was constructed in 1967 for the Montreal Expo, and was dubbed, the "Montreal Biosphere". The structure consisted of a triangulated steel space frame with acrylic panels. The acrylic panels were destroyed in a fire in 1976, leaving the space frame behind. Today a new structural material is available known as ethylene tetrafluoroethylene or ETFE. It is lightweight, transparent, flexible, easy to repair, noncombustible, self-cleaning, recyclable, and inexpensive. It was used for the exterior of both the Olympic Water Cube and Olympic Bird's Nest in Beijing (Arup, 2008). It has been used as an envelope in the Eden Project in the UK, and a giant ETFE envelope has been proposed for enclosing the skyscrapers in the city of Houston in the USA (Discovery Channel, 2009). However, there are two fundamental problems with free-standing Buckminster Fuller envelopes. First, they require a massive support frame, and second, they must be constructed all at once. In the greenplex paradigm (see Figure 1), ETFE is used to span the gaps between buildings. Thus, the roofs of the buildings are part of the envelope. A massive support frame is not needed. Greenplexes may also be constructed incrementally (see Figure 2) rather than all at once. Thus, greenplexes can grow just as cities grow today. As each building is added, the envelope and skybridges are extended to include the new building. This implies that each building must be designed to support future skybridges and envelope that span gaps between future buildings.

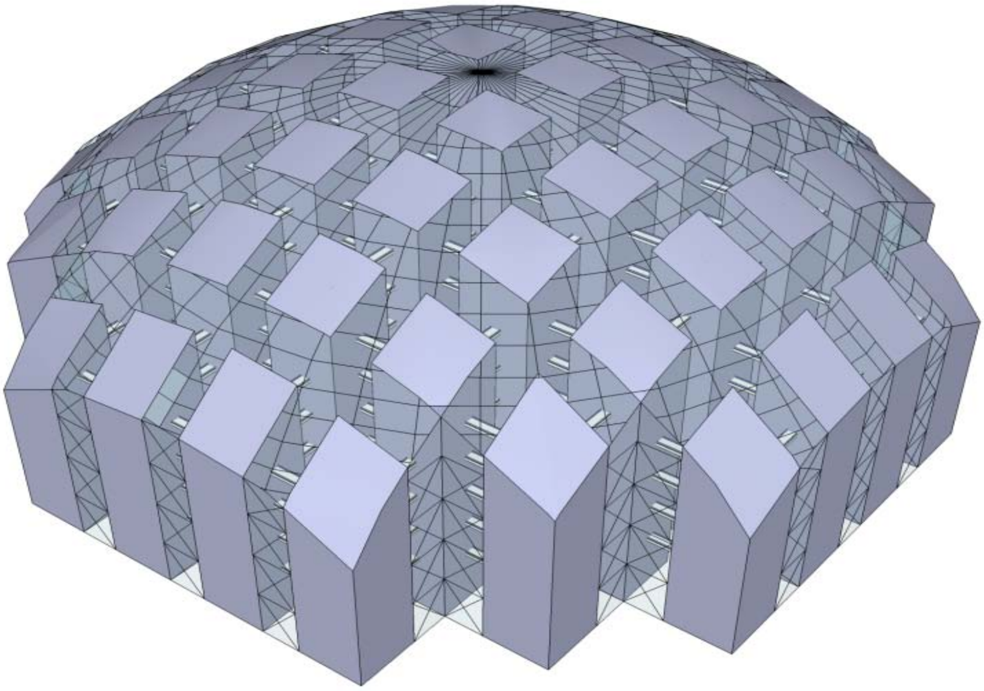

Figure 1: A Dome Greenplex

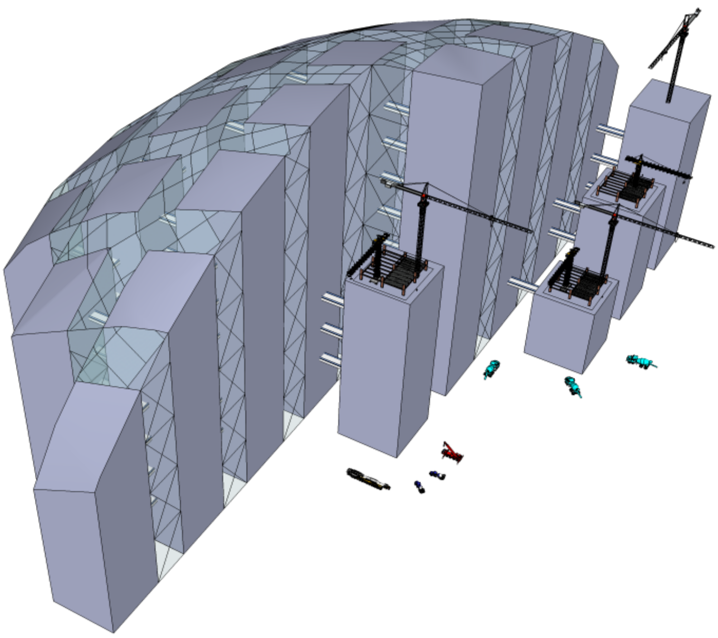

Figure 2: Incremental Construction

The second element of the greenplex paradigm is the concept of the skybridges. Skybridges have been used in cities throughout the world, notably Hong Kong, Calgary, and Las Vegas. However, they have not been used to the extent advocated by the greenplex paradigm where skybridges are used at multiple levels, say every ten stories, in both horizontal directions. Skybridges create a three-dimensional walkable community. Besides conventional walkways, the skybridges could support moving walkways and even electric trains. Vertical movement in the transportation network is achieved through elevators and stairways. Some of the elevators and trains might be designated as express for faster movement. Because the greenplex is enclosed in an envelope, it is clear that internal combustion vehicles cannot be allowed. This will greatly reduce traffic accidents and insurance costs. Furthermore, the ground level streets in the greenplex can be transformed into garden paths. What a contrast with the congested streets in the 20th century urban paradigm.

The third element of the greenplex paradigm is to sustain the buildings with green technologies. Ground source heat pumps will be used to take advantage of the relative constant temperature in the ground as a heat source in the winter and a heat sink in the summer. Hydronic heating and cooling circulates fluid in the thermally active walls and slabs of the structure, thus eliminating wasted space, noise, dust, maintenance, and inefficiency of traditional forced air duct systems (Moe, 2010). Onsite wastewater treatment has been required for new buildings in Japan (Gaulke, 2006), and would be used in the greenplex paradigm. Solar and wind energy can be harvested, and rainwater and condensation can be collected on the exterior surfaces of the greenplex.

The greenplex is a paradigm that allows for architectural diversity. The size of the greenplex may range from a few buildings to a university campus or to an entire city. The external shape of the greenplex may be a dome, a box, a pyramid, a cylinder, a cone, or any combination. In fact, the shape of the exterior envelope can be any geometric surface complimentary to the local topography and culture. The form and shape of the individual buildings in the greenplex are unrestricted as long as the heights of the buildings conform to the master plan envelope chosen by the campus or community (see Figure 3).

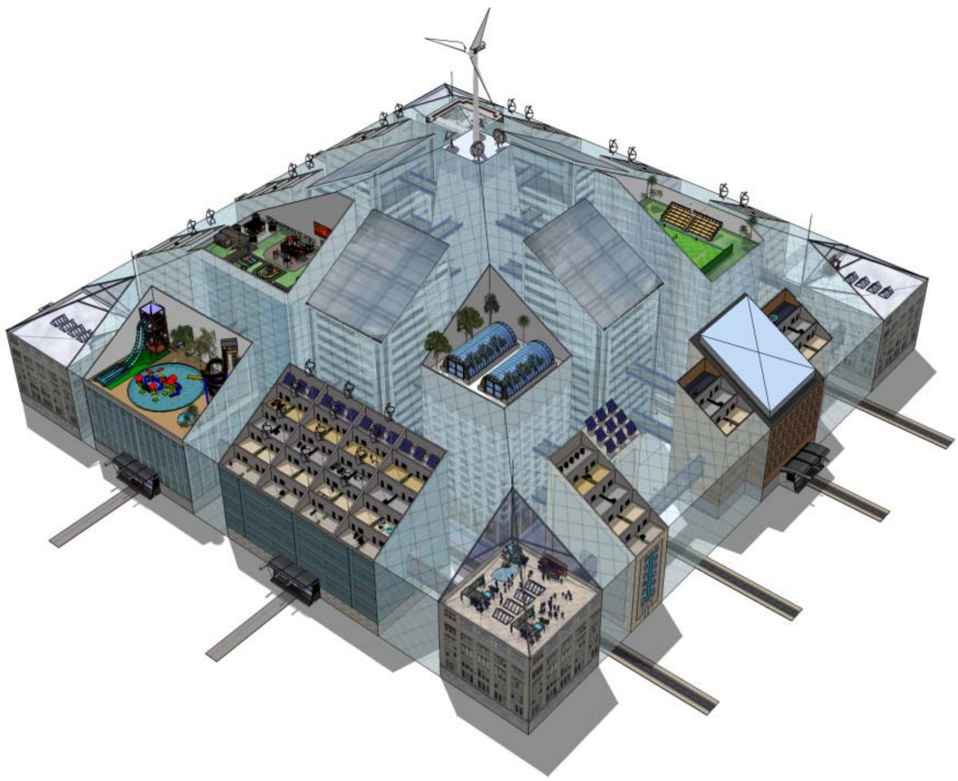

Figure 3: A Pyramid Greenplex

Will people want to live in a greenplex? That depends on whether people have a correct understanding of what a greenplex is. A greenplex is not a monolithic mall, but rather a collection of diverse buildings, each with its own view. Thus, the greenplex will have the same feel as our current cities except that the weather is always perfect inside the greenplex, noise and congestion are absent, and the greenplex is more safe since it provides multiple escape/access routes. The gaps between the buildings of the greenplex are very important for livability. The gaps provide natural light penetration, a sense of openness, natural air circulation, and fire isolation.

Existing Near Greenplexes

It is difficult to find existing structures that employ all three elements of the greenplex paradigm, namely: 1) tall buildings connected with skybridges at multiple levels, 2) an envelope that is supported by the buildings themselves, and 3) green technologies that sustain the buildings. However, two structures in Beijing deserve special attention.

Parkview Green (see Figure 4) is scheduled to open in 2011, and has been pre-certified for LEED platinum rating, the highest rating given by the U.S.Green Building Council. The project was designed by Integrated Design Associates and Arup Engineers. The project consists of two 18-story and two 9-story buildings which support a quarter-pyramid envelope 87m tall. The sides of the envelope consist of triple-glazed glass, and the roof consists of ETFE. The ETFE roof is capable of venting air (breathing) on hot summer days. It also collects rainwater. The ceilings in all levels of the buildings are water-chilled thermal surfaces. The interior buildings are interconnected with skybridges, including a remarkable cable-stayed bridge spanning the entire length of the structure. The buildings include retail shopping, first-class office space, and a luxury hotel. No residential space is included.

Figure 4: Parkview Green, Beijing

The Linked Hybrid (see Figure 5) opened in 2008 and was named best skyscraper of the year by the Council on Tall Buildings and Urban Habitat (Kamin, 2009). It was designed by Steven Holl Architects and consists of nine buildings interconnected with skybridges at about the 20th story level. The buildings include 50 apartments, a hotel, a cinema, a kindergarten, a Montessori school, recreational facilities, commercial zones, and public green space. Recycled greywater is used to irrigate the green space area. The project sits atop one of the largest ground source heat pump systems in the world consisting of 660 wells 100m deep. The system exchanges 5000kw of heat energy between the building and the ground. Water is used as the exchange fluid, which is hydronically circulated in thermally active concrete slabs throughout the buildings. The scale of this geothermal endeavor required the design team to make certain that the heat exchange would not affect the long-term ground temperature, and disrupt existing ecosystems. Obviously this project does not include an envelope.

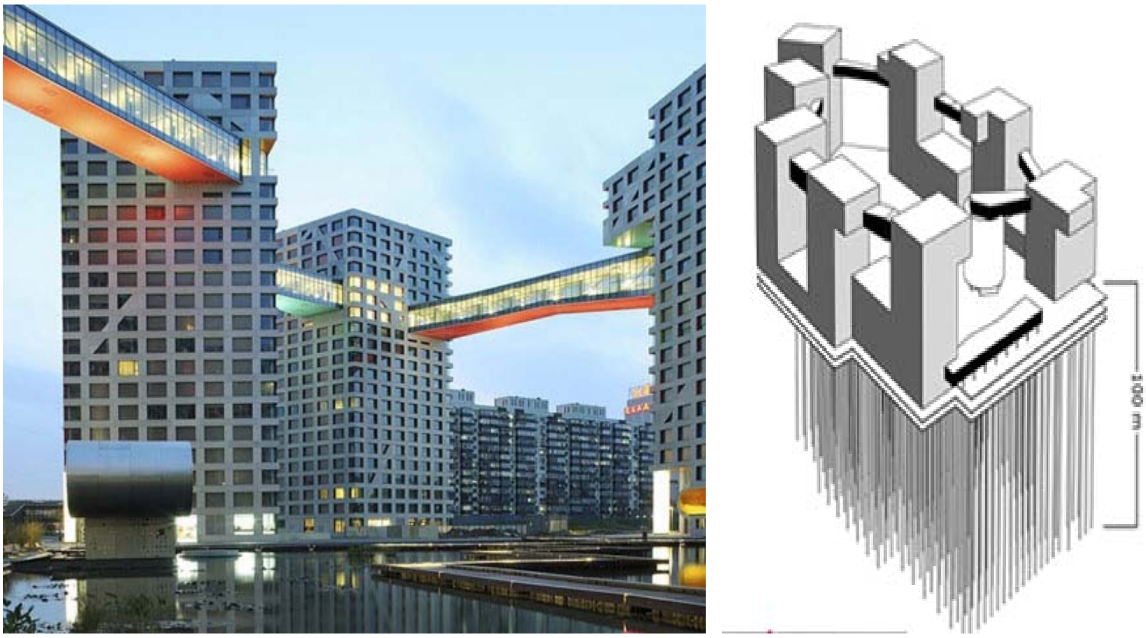

Figure 5: Linked Hybrid, Beijing

Greenplex Research

Greenplex research at Brigham Young University is directed at answering four basic questions. The first is, "Does a greenplex require less structural material than disconnected exposed skyscrapers?" At first glance, it would seem that a greenplex would require more structural material to support the skybridges and envelope. But we suspect that this is not true. This is because skyscraper design is often controlled by lateral displacement under wind loading. The total wind load on a greenplex is reduced for two reasons. First, if skyscrapers are not enclosed in an envelope, then wind load acts on each skyscraper individually. In a greenplex, wind load acts only on the external envelope. Second, the external envelope may have a more aerodynamic shape than that of tall slender skyscrapers. All the buildings in the greenplex work to resist lateral wind load because they are connected with skybridges that transmit horizontal axial force. A reduced total wind load that is resisted by the lateral stiffness of all the buildings means that the required stiffness for each building is reduced. This leads to less structural material.

The second research question is, "Can a greenplex be sustained without drawing power, water, or fuel from the grid?" Certainly, a greenplex will draw less power, water, and fuel from the grid than the current urban paradigm because the external envelope has significantly less exposed surface area than that of exposed skyscrapers. Furthermore, the three-dimensional transportation network of the greenplex leads to shorter trips and more walking. Finally, the green technologies of ground source heat pumps, hydronic heating and cooling, onsite wastewater treatment, solar/wind energy harvesting, and collection of rainwater/condensation will minimize power, water, and fuel requirements.

The third research question is, "Can a greenplex eliminate travel congestion altogether in a high density urban environment?" We intend to optimize the three dimensional transportation network of a greenplex to minimize travel time. Travel time strongly depends on space usage (residential, commercial, industrial, educational, recreational, etc). Thus, we will simultaneously optimize space usage for each 3D zone, and transport capacity for each horizontal and vertical link. We will employ a genetic algorithm to do this. We have previously used genetic algorithms to optimize land use and transportation planning for two dimensional cities (Balling, Powell, and Saito, 2004).

The fourth research question is, "How can a greenplex be designed and optimized?" A greenplex is a complex system of coupled subsystems including the structural subsystem, the transportation and use subsystem, the space conditioning subsystem, and the water and waste subsystem. The analysis of each subsystem requires input that is output from the other subsystems. There are multiple objectives for the system, namely, maximization of benefit to people, planet, and profit -- the triple bottom line of sustainability. To tackle this complex problem, we are looking at an approach known as collaborative optimization (Balling and Rawlings, 2000), which utilizes targets and discrepancies to allow subsystems to be analyzed and optimized in parallel.

Conclusions

A new urban paradigm has been defined for the 21st century, namely, the greenplex paradigm. The three elements of this paradigm are: 1) tall buildings connected with skybridges at multiple levels, 2) an envelope that is supported by the buildings themselves, and 3) green technologies that sustain the buildings. The envelope of the greenplex paradigm differs from the free-standing envelopes proposed by Buckminster Fuller and others in that the roofs of the buildings support, and are part of the envelope. ETFE is used to span the gaps between buildings. Thus, a massive support structure for the envelope is not needed, and the greenplex can be constructed incrementally, a building at a time. Greenplexes can range in size from a few buildings, to a university campus, or to an entire city. The external shape of the greenplex can be any geometric surface complimentary to the local topography and culture. The form and shape of the individual buildings in the greenplex are unrestricted as long as the heights of the buildings conform to the master plan envelope chosen by the campus or community. A greenplex is a collection of diverse buildings, each with its own view. Thus, the greenplex will have the same feel as our current cities except that the weather is always perfect inside the greenplex, noise and congestion are absent, and the greenplex is more safe since it provides multiple escape/access routes. The greenplex paradigm has the potential to significantly reduce energy consumption since its exposed surface area is far less than that of exposed skyscrapers. The three-dimensional walkable transportation network of the greenplex has the potential to reduce travel congestion altogether. The required amount of structural material in a greenplex may also be less than that of disconnected exposed skyscrapers. Modern optimization techniques including genetic algorithms and collaborative optimization are needed to efficiently design a multidisciplinary greenplex to maximize benefit to people, planet, and profit. In summary, the greenplex paradigm allows cities and campuses to plan for sustainable development.

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