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Sustainable Design Strategies for Sport Stadia

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1. Introduction

Sport stadia are some of the most complex and intricate buildings constructed throughout the world. These buildings can be extremely high energy users and take up many acres of city or countryside space. It is imperative that sustainable concepts and strategies, in design, construction, and operations, are used to help protect our environment, and contribute to the communities who house them.

In this paper, the concept of sustainable stadia will be investigated by looking at present examples, and establishing concepts and strategies for future stadia. This paper focuses on large outdoor style stadia. While indoor arenas have plenty of sustainable features to note, and room for improvement, they will not be covered in this paper. The modern stadia examined in this paper are ones that were built within the last 5 years or so, with a focus in design as a sustainable stadium. The case studies will provide the most up to date approach on sustainable techniques in stadium design and operation.

Approaches that have yet to be used in sustainable stadium design, construction, and operations will be explored and examined. The ultimate goal of the paper is to develop concepts and strategies for new and existing stadia to make their buildings more efficient and sustainable for the communities. The focus is on how these stadia can best contribute to the communities who house them and share the relationship that dates back millennia.

This study investigates a variety of techniques for sustainable stadium design, covering new construction and existing stadia. This not only gives new stadia the opportunity to learn from the past but also creates a very shallow learning curve. Using data to provide quantifiable measures of sustainability in stadia design and operation will verify how important and useful it will be to create a new generation of sustainable stadia, for the players, the fans, and the surrounding community.

2. Background

In this section, the current techniques in sustainable stadia design development will be reviewed utilizing main cited projects from around the world. These stadia are some of the most advanced sustainable stadiums to date, and are a building block for future stadia. Stadia today have tremendous effects on resourced consumption in their communities. Not only are natural resources (land, water, energy production, food) consumed at high rates, these stadia also include large amount of waste generation, large movements of people and other sustainability issues that can be addressed with proper stadium development. The topics learned in this section to help combat these sustainability issues, will help shape the discussion and analysis of how future stadia can improve upon the sustainable techniques utilized in these stadia. The table below illustrates information about the three stadia examined in this section.

Table 1: Basic Data about Stadia Projects Studied

Name, Country	Current Functions	Capacity (People)	Annual Event Days	Year Built
National Stadium, Taiwan	Multi-use and Soccer Stadium	50,000	20	2009
Olympic Stadium, England	Multi-use and Soccer Stadium	28,000	50	2012
Marlins Park, USA	Baseball Stadium	37,442	100	2012

2.1 National Stadium: Kaohsiung, Taiwan

Figure 1: National Stadium (Peellden 2009)

The National Stadium in Taiwan was built for the 2009 World Games. From the inception of the project, Japanese architect Toyo Ito set out to design the world's first solar powered stadium. That stadium was truly a success. The dragon shaped stadium, holds 50,000 seats and sits on a 19 hectare open space created in addition to the stadium. An image of the stadium and the surrounding green space can be seen in Figure 1, above.

The stadium is comprised of 8,844 solar panels which creates approximately 1.14 million KWh per year (Pham 2014). This electricity can power 100% of the energy used during game/event days. On non-game/event days the Taiwanese government plans to feed the electricity created by the solar panels to the grid. This electricity can meet almost 80% of the surrounding neighborhoods requirements. The creative use of solar panels to depict the scales of a dragon is not only visually stimulating, it provides a much needed positive impact to the community. The Taiwanese government claims that the renewable energy

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generated at the National Stadium will save 660 tons of carbon dioxide each year (New Solar Stadium in Taiwan 2009).

The sustainable design strategies do not end there. The stadium also utilized only raw materials sourced from Taiwan in the construction of the stadium. These materials are also 100% reusable if need be. Within the 19 hectares of public space, 7 hectares have been specifically set aside as public green space. This space includes bike paths, sport parks, an ecological park and more. Additionally, all plants occupying the area of the stadium have been transplanted and new tropical plants and palm trees were planted as well (New Solar Stadium in Taiwan 2009).

The sustainable strategies used to design and build this stadium were quite innovative at the time. The stadium is still the largest solar powered stadium in the world and proves that using renewable energy for a large scale stadium can certainly be a success. This earlier innovator has proven that sustainable design can be beautiful, have a positive community connection, and have little to no impact on the environment.

2.2 Olympic Park: London, England

Figure 2: London Olympic Stadium (BaldBoris 2012)

In 2005 London won the bid to host the Olympic Games. From the very beginning, the organizers knew that they wanted the 2012 Olympic Games to be the greenest Olympic Games ever played. The Sydney and Athens Games had set a good example for sustainability, but it was London's goal to set the new standard. The site for the Olympic stadium would be just outside of central London in a brownfield. The idea was to use the Olympic Games as a catalyst for redevelopment of this area. The Olympic Stadium and surrounding Queen Elizabeth Olympic Park would be the launching point for a new highly sustainable neighborhood. An image of the completed stadium can be seen in Figure 2, above.

While sustainable efforts can be seen all across the games, the Olympic Stadium would be the spotlight of success. As with many Olympic Games of the past, the question always stands with how to proceed with life after the Games. Examples in Montreal and Barcelona have shown large stadia that were too expensive to build and not properly, or at all, utilized after the games. This creates a huge burden on the host cities for decades to come. One of the most important design elements, that would help avoid this problem for the Olympic Stadium, was the creation of a removable upper deck.

During the games, the Olympic Stadium hosted the opening and closing ceremonies, along with athletic competitions. For the twelve day span of the Olympic Games, the stadium could seat up to 80,000 spectators. The upper ring of the stadium was removed and recycled after the Games to make the Olympic Stadium more manageable for future use and now holds 28,000 spectators. The main use for the stadium now will be large concerts, events, and other athletic events, including the 2017 IAFF World Athletics Championships.

There are numerous other sustainable design features, outside of the removable upper tier, that went into the formation of the Olympic Stadium. Starting with the construction stage, the stadium had almost no construction waste sent to landfills. "More than 98% of the demolition waste from decrepit buildings that were torn down was recycled" (International Olympic Committee 2013). Most of the waste was recycled, reused, or sent to the waste-to-energy center. According the architects, Populous, who designed the stadium:

> *The stadium, and master plan as a whole, have taken a new, sustainable approach to the temporary architecture – we use only the materials, structure and operational systems needed for the event, then transform it for long-term us* (Populous 2012).

In order to achieve this result, Populous set out to create the lightest-weight stadium ever constructed. Reducing the amount of material needed to build Olympic Stadium was one of the first steps in making it a sustainable stadium. Most materials need to travel from far away to arrive at a construction site; all transportation options (some more than others) emit greenhouse gases. By reducing the amount of material needed to build the stadium, the design team began limiting the stadium's impact on the environment. Additionally, "to reduce the environmental impact of the massive construction project, workers dredged the River Lea to create a canal network that was used to transport construction materials to the site" (International Olympic Committee 2013). This effort helped eliminate thousands of tons of greenhouse gases.

London's Olympic Stadium was designed, and constructed, to use less than half the steel of comparable stadia, making it the lightest Olympic stadium to date. The stadium was also built with more than one third of the material coming from recycled content. For example, the ring beams that support the roof are made from reclaimed gas pipes (Shankleman 2012). The roof for the stadium is built from PVC as opposed to traditional methods of steel or concrete. This again helps reduce the weight (driving cost and greenhouse gas emissions down) and makes the stadium more recyclable once it has outdated itself.

The stadium includes a water harvesting system that utilizes the available non-potable water for multiple uses. Additionally, the stadium has separate potable and non-potable water networks. These tie into the water harvesting system and help reduce the water demand on the stadium by reusing harvested rainwater to irrigate the field, flush toilets, etc. London gets a fair amount of rain yearly, so it makes great sense to reuse the water instead of creating an added burden on the community. London's Olympic Stadium, and surrounding venues, is committed to reducing the water use 40% over traditional means (London Legacy Development Corporation 2012).

Solar panels were also used on site to help lower the electricity needs of the stadium. There are solar panels covering the press center roof and many of the car parks. This electricity is used for day to day operations and could be sold back to the grid to help lower the cost of electricity to the newly created sustainable neighborhood surrounding the stadium.

These features plus low-tech passive design strategies help the Olympic Stadium be one of the best current examples of the sustainable stadia. However the stadium is just one small part of the overall site that has helped to revitalize an underappreciated area. The site for the stadium sits on a remediated and restored brownfield (London Legacy Development Corporation 2012). What once held mountains of broken refrigerators is now a beautiful, sustainably developed and operated park system. The previous brownfield site had little to no natural spaces that were safe for locals. The waterways were in poor condition, and the area was rundown with invasive species.

The creation of the Olympic Stadium in the area helped to change all that. The site now holds over 45 hectares of bio-diverse parkland and 6.5km of waterways, 3 km of water ways which were restored to create a healthy area for people, plants and animals (London Legacy Development Corporation 2012). Over 300,000 plants were planted in the Olympic Park wetland area to restore the biodiversity of the area (International Olympic Committee 2013). The restoration of this area will also allow for the use of new sustainable transportation methods into the city center. A number of water taxis will be available for commuting and recreational purposes. Biking paths in and around the site help lower greenhouse gases and provide fun and safe ways to reach the stadium.

Two other unique sustainable features that were developed on site for the Olympic Stadium and surrounding area are the Energy Center and the Waste Water Treatment Plant. The Energy Center was built to house the waste-to-energy program. Instead of using the landfills for waste disposal, the Energy Center is a biomass boiler that uses wood chips to burn the waste creating both heat and energy from waste. The heat is sent to the stadium and nearby homes, and the energy produced is used in the surrounding areas as well. While all incinerators emit some greenhouse gases, the benefits from the waste-to-energy plan strongly outweigh other (landfill) waste disposal options. The Energy Scheme was designed to serve the 2012 London Games and up to 11,000 homes, two million square feet of commercial space, retail venues (such as the Olympic Stadium), Statford City, and surrounding developments (London Legacy Development Corporation 2012).

The water system for the stadium and surrounding areas uses as much non-potable water as possible. The system has been successfully integrated into the Thames Water black water treatment and grey water treatment plant which enables low potable water use for the community (London Legacy Development Corporation 2012). In addition to using the Thames Water treatment, a state of the art facility was built which takes sewage from Great Northern Outfall Sewer and treats it for irrigating the Olympic Stadium, Queen Elizabeth Olympic Park, and toilet flushing for the venues (London Legacy Development Corporation 2012).

London's Olympic Stadium and the surrounding Queen Elizabeth Olympic Park are a model for success for sustainable stadia design. The flexibility of the design allowed the stadium to be relevant after the games were over, and the site selection helped rejuvenate an area that was in desperate need of attention. The design of the stadium and surrounding areas showed how sustainable an Olympic Games could be and inspired a new sustainable neighborhood which will be a beacon of environmental stewardship. Thanks to these efforts the 2012 Games generated 28% less CO_2 emissions than forecasted and once the games were over 99% of waste from installing and decommissioning Games venues was reused or recycled (International Olympic Committee 2013). London's Olympic Stadium is a demonstration and inspiration of sustainable design for years to come.

2.3: Case Study – Marlins Park: Miami, FL

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Figure 3: Marlins Park (Illmatic 2013)

Marlins Park was built in 2012 to be the home stadium of Major League Baseball's Miami Marlins. Located in the Little Havana neighborhood, just a few miles from the heart of downtown Miami, this new stadium has achieved LEED Gold, and is an exceptional stadium from both an environmental stewardship and engineering marvel aspects. Marlins Park seats 37,442 (third smallest stadium in the MLB) spectators under a retractable roof, making it the first retractable roof stadium in the world to achieve LEED certification. An image of the stadium and retractable roof can be seen in Figure 3, above.

Marlins Park was able to achieve recognition in its success utilizing sustainable design elements by:

> *incorporating a comprehensive sustainability strategy throughout the design including site selection benefits, water use reduction, energy use reduction, an event recycling program, regionally-sourced and recycled content materials, construction waste management, and care in design of healthy interior environments* (Miami Marlins 2014).

There were many challenges to designing a stadium in the South Florida, including but not limited to: intense summer heat, heavy daily rains, finding enough space in an urban setting, environmental considerations, and the threat of tropical storms and hurricanes every year. The architects and engineers tackled each of these problems using and integrated approach, to create a (sometimes) open air stadium with a beautiful view of Miami.

Marlins Park was built on the site where a previous stadium (Orange Bowl) once stood, creating essentially an infill stadium. The architect's plan was to recreate "the neighbourhood street network and reconnect Little Havana to the main public streets” (John, Sheard and Vickery 2013). The desire was that the stadium would regenerate the life, economics, culture, and social aspects of the neighborhood. Marlins Park has two public plazas, one on the east side and one on the west side. The west side plaza is covered when the roof is open, changing the feel of the plaza. Marlin’s Park retail base is used “to integrate with the proposed adjacent retail development, intentionally creating a street edge that connects to the surrounding neighbourhood” according to the architecture firm, Populous, who designed the stadium.

Since the site was an infill from the previous stadium, many of the infrastructure needs were already in place. The Marlins Ballpark District already included “four city of Miami public parking garages, which cover more than 72% of parking spaces from the intense Florida sun (Miami Marlins 2014). They also installed 319 bike racks and used the current city bus lines to help create more sustainable transportation options to the stadium. The existence of the parking garages was essential not just from a cost savings perspective, but from an economic development perspective as well. For the team to grow their fan base, they must provide appropriate and comfortable methods to reach and exit the stadium.

The retractable roof is not only stunning, but is considered a “cool roof’. The white reflective roofing material helps reduce the heat island effect and the reflectivity also helps reduce heat gain, lowering the demand for air conditioning. (Miami Marlins 2014).

Marlins Park incorporated many water efficiency programs into the design of the stadium. According to the Marlins’ website, the “pluming fixture design and operational strategies will reduce water use by an estimated 52% when compared against a similar project” (Miami Marlins 2014). These fixtures include waterless urinals, low flow water closets, restroom faucets, showerheads, etc. Other innovative ideas to reduce water include the use of ultraviolet light, in the concessions area, to help prevent the buildup of grease from cooking food (O'Connor 2011). The prevention of buildup in turn helps reduce the water usage by not needing as much water to clean the grease after every game (at least 82 per year).

Landscape design, when not done properly, can lead to the usage of incredible amounts of excess water. The designers were certainly aware of this when creating the landscape design for the stadium. The design used native plant species, as well as species which have low water demands in order to achieve a 60% potable water use reduction for irrigation purposes when compared to a similar project (Populous 2012).

Much of the sustainable design aspect of the stadium comes from the passive design techniques that were used to create the building envelope, and the main feature being the retractable roof. Due to the intense heat and frequent occurrences of rain fall, the stadium designers incorporated a retractable roof. The goal being if the conditions were too hot or too wet, the game can still be played keeping both the spectators and athletes safe and comfortable. However “due to the way air pressure inside the stadium changes when the roof opens, Marlins Park had to be strategic about ventilation. The solution was to create a massive operable glass wall in the outfield that will open whenever the roof is open (O'Connor 2011). This operable wall is also an innovative design feature inside the stadium in that it gives the spectators beautiful views of downtown Miami.

This combination of beauty and sustainable features is a true mark of success for Marlins Park, and one that other stadia around the world will seek to mimic. Marlins Park, through the thoughtful design of the building envelope as well as the mechanical, electrical, lighting, heating and cooling systems, achieved a 22.4% (by cost) energy use reduction when compared against a similar project (Populous 2012). Such innovations include the regenerative drive system used to open and close the 8,000 ton retractable roof. Normally a roof of this size and weight would be quite expensive and use a large amount of energy to operate, however by using the regenerative drive system, the power consumption is reduced. The roof cost less than $10 in electricity to open or close (Berg 2014). Also to minimize greenhouse gas effects the refrigeration systems at Marlins Park use no CFC-based refrigerants. This trend can be seen in most modern buildings and is a direct result from the Montreal Protocol established in 1987.

The lighting in stadia worldwide must satisfy today’s high definition broadcasting needs. However brighter lights typically mean more power and more power means more electricity and more money, neither are ideals for new stadia. Marlins Park used Green Generation Lighting which will enhance the lighting for spectators and television viewers while cutting energy cost and minimally impacting the environment. All lamps are aimed digitally within 0.15 degree of accuracy, maximizing the quantity and quality of the lighting system (Miami Marlins 2014). This reduces the over utilization of lights by digitally placing them in the exact spots needed for proper coverage.

There were three main focus points for material and resource reduction both pre-building construction and post-building construction (operations). Marlins Park used the help of local companies to divert or recycle more than 75% of construction waste from landfills (Miami Marlins 2014). Some numbers indicate that the diversion rate was as high as 97% (O'Connor 2011). It is known that over 50% of landfill waste comes from construction related activities in the United

States. Marlins Park is setting the standard on how stadia can help reduce their impact on this issue. Also, more than half of the total material used in the construction of Marlins Park was locally sourced to help reduce the emissions of greenhouse gases.

From an operations standpoint, Marlins Park implemented a comprehensive Event Recycling Plan to ensure that the stadium will be one of the leaders in recycling efforts throughout the MLB. (Populous 2012). All the cutlery and concession packaging material are either recyclable or composed of recycled materials. Marlins Park has placed numerous recycling containers to collect plastic, metals, paper, cardboard, and glass throughout the concourses and in the East and West Plazas as well.

Marlins Park has continued the recycling efforts by holding e-waste recycling days. Fans receive free tickets by bringing old, broken, used, or outdated electronics to the stadium for proper disposal. E-waste includes cell phones, computers, TV's, game consoles, printers, VCR's, stereos, and radios. (Miami Marlins 2013). The Marlins also take place in the Rock and Wrap It Up! program that sends unsold food to the community after games days. In one month's span the Marlins delivered more than 4,500 pounds of food to a local senior center. This is a marvelous way for the stadium to give back to the community who helped fund the stadium.

As in most new sustainable buildings personal control over thermostats and lighting helps reduce the over usage of such things. Marlins Park has designed the thermal and lighting systems to be able to be adjusted to suit individual or space needs (Populous 2012). The stadium is also a smoke-free environment, even when the roof is open; helping to improve the air quality of the spectators, employees, and athletes. Lastly all paints, coatings, sealants, adhesives, carpet systems, and wood components used in Marlins Park are low-emitting interior finish materials giving employees and visitors a healthy indoor environment (Miami Marlins 2014).

With all of the great sustainable features used to design, build, and operate Marlins Park, there are still a few areas for improvement. The greatest concern for the building is the location. Infilling the site of the Orange Bowl provided a number of positive aspects for the stadium; however it does not address the great concern of sea level rise. The image below shows "a rendering of what the neighborhood surrounding Marlins Park… could look like after three feet of sea-level rise, based on data from ClimateCentral.org's Surging Seas research" (Roston 2014). The modern stadium is designed to last 50-75 years. Marlins Park may not make it that long if the seas grow as expected. Stadium owners need to

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look at long term sea-level rise projections when establishing the footprint and location of new stadia. Marlins stadium is designed with 27 flood gates built one foot higher than the 500 year flood plain (Roston 2014); however it would be impossible to reach the stadium if the predictions hold true, along with numerous other issues.

Figure 4: Greater Miami with 3 Foot Increase in Sea Level (High Water Line, Toro and Climate Central 2013)

Also, even though there are a number of bus stops that connect near by the stadium, it can often be a long walk from bus stop to stadium. When dealing with the heat or rain of South Florida, this can definitely be a deterrent from using public transportation. Providing shuttles or pedi-cab services would be an excellent way to bridge this gap.

There is no mention of using any sort of water collection to irrigate the field or utilizing non-potable water for field irrigation. As mentioned earlier professional field can use up to 20,000 liters a day to maintain proper form. With the amount of rainfall that takes place in South Florida, there is no reason that Marlins Park should need to use any potable water for field irrigation. This is clearly an area for future improvements to the stadium.

3. Concepts and Strategies for Sustainable Stadia

The following section cover concepts and strategies for sustainable stadia that go beyond the initiatives covered in the case studies. While the case studies provide an excellent framework for sustainable initiatives, this section expands on the opportunities of sustainable design, construction, and operation, while also providing quantifiable data that demonstrates the benefits of utilizing sustainable design techniques throughout the life cycle of the stadium**.**

Table 2 below outlines some of the typical challenges often found when designing and operating large outdoor stadia, and the proposed design solutions.

Table 2: Summary of the Main Challenges in Designing and Operating Stadia along with Suggested Solutions

Challenges Faced in Stadium Design and Operation	Strategies for Success
Large Energy Consumption on Event Days	Passive Design, On-site Renewable Energy, Green Roofs, Alternative Transportation Methods, LED Lights, Building Automation Systems
Large Water Consumption Year Around	On-site Water Retention, Increased Non-potable Water Usage, Low Flow Fixtures and Fittings, Native Landscaping
Large Material Usage in Construction and Operations	Light-weight Design, Recycled or Post-consumer Materials, Locally Sourced Material, Rapidly Renewable Material, Sustainable Purchasing Plan
Large Waste Streams	Recycling and Composting Initiatives, Food Waste Donations, E-waste Drives, Durable Good Donations
Community Engagement	Showcase Local Foods and Products, Incentives for Alternative Commuting, Stadium Tours and Education

When dealing with new stadia in particular, utilizing an integrated design process is of paramount importance in properly developing and integrating the above strategies into the stadium design. Additionally, analyzing the strategic environmental assessment [SEA] early in the design processes is the most cost-effective and efficient means of mitigating the environmental effects of any particular development, particularly a macro infrastructure project such as a Stadium development (Morrissey, et al. 2013). The SEA seeks to address they key questions of:

- What are the potential direct and indirect outcomes for the development?
- How do these outcomes interact with the environment?
- What is the scope and nature of these interactions?
- How might environmental effects be limited through mitigation strategies and risks minimized through adaptation strategies?
- What is the overall effect of the proposal after mitigation and adaptation strategies have been adopted?

It is critical that these questions be analyzed and understood by the entire project team, as the decisions made in terms of what sustainable strategies to employ should be the ones that best assist mitigate the overall environmental impact of the project.

3.1 Energy Usage

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Energy consumption is one of the greatest concerns for large sport stadia. Even though they are often infrequently used, the amount of energy used during a single game can be quite massive. The San Francisco 49er's new stadium has installed over 1,000 solar panels which will only meet the energy needs of the stadium during game days (approximately 8-10 per year). Suffice it to say that the stadium needs energy the other 355 days in the year. There are tours, maintenance, cleaning, offices, etc. that all use energy year around. Energy use in stadia come from a variety of sources – Lighting, HVAC systems, concessions, cleaning, etc.; minimizing both demand side and supply side sources is key to creating a sustainable stadium. Supply side energy efficiency measures are those which affect the supply of energy to the stadium, such as renewable energy. Demand side energy efficiency measures are those which affect how much energy is being used in the stadium during operation. Although both should be considered when building a sustainable stadium, demand side energy efficiency measures are often more easily implemented in existing buildings as they often do not require large capital expenditures.

The following are concepts and strategies for both new stadia and retrofits of existing stadia that can help minimize energy needs year around, with the ultimate goal of being net-zero energy users or better yet net-positive energy users (creating more energy than used on site), which enable stadia to give energy back to the community. This idea is fundamental as some stadia can use as much energy in one game as it takes to power 910 homes for an entire year.

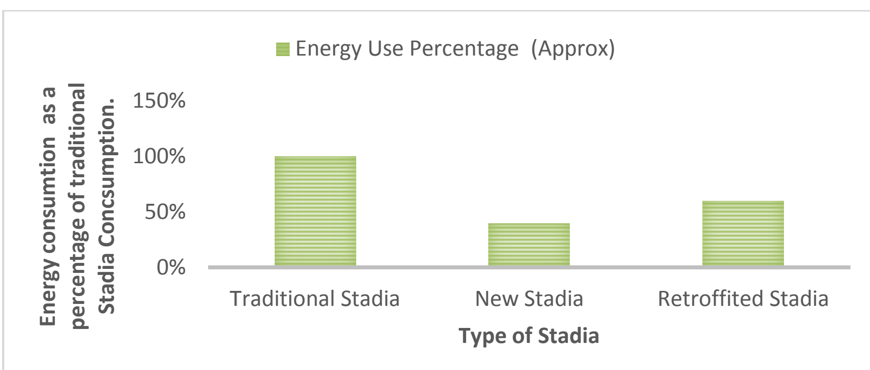

Figure 4: Comparison of Energy Usage for Traditional and Non-Traditional Stadia

New and retrofitted stadia can use significantly less energy than traditional stadia. New stadia could use from one third to half the energy of the traditional stadia, in both construction and operations, (20% energy reduction using passive design, 25% reduction using renewable energy, 10% reduction from transportation reduction, and 5% reduction from green roof) and examples of retrofitted stadium currently show that they use 24% less energy (Philadelphia Eagles 2014) and after the suggested retrofits this can increase to 40% energy savings (increased 10% from transportation reduction, and 5% from green roofs) (see Figure 4).

3.1.1: Energy Efficiency Reduction Opportunities for New Stadia

When designing a new sport stadium, minimizing energy is a must, both from a cost and an environmental stewardship perspective. New stadia allow for many diverse options in terms of energy reductions. The embodied energy of a stadium (the total energy spent in the production of a building) can average about 1,380 MBtu/sf (Booz, Allen, & Hamilton 1979). The Cowboys Stadium (2.3 million square feet) used about 930,200 MWhr of energy to build. The first and most important energy saving technique in stadia is passive design. Passive design can help reduce energy consumption and cost by as much as 20% (City of Cape Town 2010). Not many stadia in the past have used passive design techniques, but lately (see Case Study 3.4) some stadia have included this design technique as a key concept. Lowering the playing field below ground level is one of the most important design elements can help in a variety of ways. It can benefit reduce material cost, can to help keep the pitch cooler, and with proper ventilation techniques can assist to keep the spectators, employees, and athletes cooler as well.

All these advantages also help reduce the energy consumption of a stadium. From a construction standpoint, limiting the material needed will limit the amount of energy (and greenhouse gases) needed during the construction phase. Natural ventilation is essential for spectator comfort and safety, but also helps reduce energy consumption by eliminating or reducing the need for large HVAC systems, fans, or other cooling devices. Even outdoor stadia use HVAC systems in the offices, press boxes, suites, etc. A stadium suite that is naturally ventilated, not only saves energy, but can create better viewing experience and connection to the game for the fans. Passive design techniques can also contribute appreciably to reduction in the amount of artificial lighting necessary for the stadium.

There are essentially three different lighting areas in a stadium. There is the lighting for the playing surface that is only used for evening and night games, there is the lighting in the concourses, and there is lighting for the offices, suites, bathrooms, etc. Due to the multiple uses, lighting is by far the largest contributor of energy usage in sport stadia (Muller and Green Sports Alliance 2015). Passive design can help decrease energy consumption with all the lighting schemes. Allowing light to penetrate into the offices, suites, and concourse can greatly reduce the energy used for lighting during the day. Proper sun lighting is also needed for games which are played in the early afternoon. Using high efficiency lights, such as LED’s, can help reduce energy costs associated with lighting as

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these lights have less loss due to heat versus conventional lights. The lights used to illuminate the playing surface need to be very strong and up to strict television standards. Nevertheless, these lights can also be high efficiency and like in the case of the Miami Marlins, the light placement can be digitally controlled to eliminate over use of lights. A translucent roof is an excellent strategy to help produce shade for the spectators and also reduce the amount of artificial light needed for the stadium.

Another energy saving technique that is not widely applied in large sport stadia is on-site renewable energy. This can include solar panels, wind turbines, biomass, hydro, etc. Solar panels are becoming more common in new stadia design, but not yet being used to its full potential. Solar panels don't have to be secluded to the roofs; they can be used on the sides of the buildings or on top of car parks/parking lots. The use of solar panels as covered parking should become the standard for large aboveground parking lots. The average NFL stadium has approximately 1 parking spot for every 3 fans (Rosenberg 2014). Assuming a stadium has 45,000 seats, the amount of power generation for all the parking to be covered by solar panels can be seen below.

$$Average\ Area\ of\ a\ Parking\ Space\ in\ the\ United\ States = 9'w\ by\ 18'l = 162\ sq.ft.$$

$$Average\ Power\ Generation\ per\ Square\ Foot\ for\ Mondern\ Solar\ Panels = 8 - 10\ watts$$

$$162\ sq.ft.\ x\ 15{,}000\ spaces = 2{,}430{,}000\ sq.ft$$

$$2{,}430{,}000\ sq.ft\ x\ 8\ Watts = 19{,}440{,}000\ Watts = 19{,}440\ kW = \mathbf{19.44\ MW}$$

$$19.44\ MW\ x\ 2920\ \frac{(sunlight)\ hours}{year} = 56{,}764.8\ MWhr/year$$

(CT, Danbury n.d.), (Solar & Wind Energy Calculations: The (very) Basics 2014)

AT&T Stadium, in Dallas, Texas, uses roughly 24,439.9 MWhr per year (Glubiak 2009). With this use of covered parking for 15,000 parking spaces most stadia could more than cover more than a year's worth of energy consumption at the stadium. This leads to 32,324.9 MWhr per year that can be sold back to the grid and used to provide the community with affordable renewable energy. This electricity can be given to low income housing, schools, or other municipal buildings.

Very few stadia have incorporated wind turbines as a renewable energy source. The efficiency of wind turbines is a maximum of 59.3% according to the German physicist Albert Betz when in an ideal condition. Even though the ideal conditions do not always exist, it still is a better alternative compared to conventional energy generation and an effective way lowering energy consumption from fossil fuels. Another option for on-site renewable energy is a biomass. Waste generated during games could be burned to create both heat and electricity. Many cities rely on district heating systems during the winter. A stadium with an on-site incinerator could eliminate waste from game days and act as a waste-to-energy project for the community year around. As seen from the Copenhagen incinerators, one ton of waste can produce 4 kW of energy and 3 kW of heat. This is a prime example of a stadium giving back to the community.

Green roofs are another excellent way to reduce energy consumption, reduce the amount of greenhouse gases emitted, and help reduce heat island effect. A green roof can help lower the indoor temperature by up to 5°F, which can lead to energy saving of 5% (Energy Star 2005). Green roofs are slowly appearing in different stadia around the world, but the inclusion of green walls has not come so far. Green walls can provide the same cooling effect as green roofs and also add a layer of architectural design and uniqueness to a stadium.

Another major sector of energy usage is transportation to and from sport stadia. These massive building can, at times, hold up 80,000 spectators, not including employees, athletes, coaches, referees, etc. All these people have to arrive at the stadium by some means, and all too often it's by automobile. Cars not only consume large amounts of energy, they emit incredible amounts of greenhouse gases. The Portland Trailblazers have established that 73% of their overall carbon emissions come from commuting - 58% from guest, 11% from employees, and 4% from business travels (Muller and Green Sports Alliance 2015). All new sustainable stadia should have comprehensive transportation management plans that aid to reduce the amount of automobiles and traffic at the stadium.

Options to reduce automobile traffic include specialized bike routes, extra public transportation options, limitation of the amount of parking spaces, carpooling incentives, etc. Sport stadia are often time located in or near the heart of the city. These stadia have many more options for public transportation and alternative transportation methods. However, some teams have unfortunately chosen to locate their stadia far outside (10+ miles) of the city for cost and other reasons. These stadia have a much more difficult time incorporating alternative transportation options to the stadia.

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Having bicycle routes to the stadia year around is the ideal option, but if not possible stadia owners should work with the local government to create game day biking options that create an alternative and safe way to get to the stadium. To the same point, stadia should have enough bicycle parking to allow for this method of transportation. If the stadium is not located near public transportation, specialized options, such as shuttle buses, should be made available during games days. Additionally, large sport stadia should make a concerted effort to minimize the amount of parking spaces made available and increase and prioritize the parking for electric vehicles. By minimizing parking spaces, the stadium is reducing its heat island effect, created more space for the community, and reducing the amount of greenhouse gases emitted by spectators. A reduction of just 1,000 cars using two less gallon of gasoline to drive to the stadium is equal to a reduction of almost 18 metric tons of CO_2 per game.

$$8.887 \, x \, 10^{-3} \, metric \; tons \; CO_2 \; per \; gallon \; of \; gasoline$$

$$8.887 \, x \, 10^{-3} \, metric \; tons \; CO_2 \; per \; gallon \; of \; gasoline \; x \; 2000 \; gallons \; of \; gasoline = \mathbf{17.74 \; metric \; tons \; of \; CO_2}$$

(EPA 2014).

3.1.2: Energy Efficiency and Reduction Opportunities for Retrofitted Stadia

Many of the previous approaches discussed can be used to retrofit stadia to make them more sustainable. Passive design techniques may not be applicable as it can be too costly or not as effective. It may prove too difficult to lower the pitch, or there may be little to no benefit depending on the original design. With regard to lighting, both indoor and outdoor lighting can be changed to reduce energy demand. Indoor lighting can be changed to LED's and can also incorporate motion detectors and occupancy sensors to help minimize usage when not needed. The lights used to illuminate the playing field can be retrofitted to be more efficient and with the digital technology that exist today. While the outdoor light change to LED can be quite costly, the ROI for this technology is only about five or six years (Sanserino 2014), much less than the life span of a traditional sport stadia, which can be up to 50 years. Improving and upgrading lighting is often a great first step for retrofitting stadia as it has the largest impact on building energy consumption.

On-site renewable energy is certainly a strategy that can be implemented post construction. Solar panels can be added to roofs, walls, car parks, or extra space surrounding the stadium. Many sport stadia have begun to introduce solar panels post construction as the need for sustainable energy, as well as the efficiency of the solar panels, increase, and the cost of solar panels decrease. Less commonly seen but still very possible, is the addition of wind turbines to a stadium. One may think that wind turbines would be an eyesore or require large amounts of land, but this is not the case anymore. Helical turbines are now being used with the same or greater efficiency than large three pronged rotational turbines.

These turbines can be mounted on the stadium roof, on light poles around the stadium, on top of the car parks, etc. These are the best solution for low wind speed and residential or commercial applications. In a proper location this turbine can have a ROI of 7.3 years (PSU n.d.). This again is much less than the lifespan of the average stadium.

Green roofs and green walls can most certainly be added to sport stadia post construction. Many stadia may have specialized roofs that cannot support the weight of a green roof, but there are often suites or luxury boxes that may have usable roofs. If a green roof is not possible there may be opportunities to add green space over car parks or around the stadium. While this will not help with lowering cooling demand, it will assist reducing heat island effect and overall greenhouse gas emissions.

All the transportation options mentioned in the new stadium section can easily be implemented in an existing stadium. Electric car and bicycling parking can be increased, bicycle friendly commuting options can be established, specialized public transportation during games days can be attained, and even the reduction of parking spaces can be achieved. More public and green spaces can be created where parking once stood. This would help reduce greenhouse gases and create a public green space for the community to utilize when the stadium is not in use. During game days this can be an excellent place for tailgating or other pre- and post-game activities.

Suffice it to say that no matter how new or old an existing stadium might be, there are still several concepts and strategies that can be implemented post-construction to help reduce the energy demand and greenhouse gas emission of the stadium. These efforts will be doubly beneficial to stadium owners as they can also drastically reduce the operations cost and electric bill of the stadium.

3.2: Water Usage

It is a well-known fact that water is a limited resource, yet many people, companies, and communities do not act with that fact in mind. It is critical that sport stadia do everything in their power to reduce water consumption as much as possible. A stadium should never put a strain on the community, it should instead help provide and sustain the community. Depending on size and location, stadia can use between 14,000,000 gallons to 51,000,000 gallons of water per year. This

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is equivalent to the amount of water use in one year by 152 to 553 homes, respectively (American Water Works Association 2014); (MLB 2014); (City of Santa Clara Water and Sewer Utilities 2009). Stadia have the opportunity to both collect and possibly distribute rain water to community for non-potable water usage. Some strategies and concepts are given below.

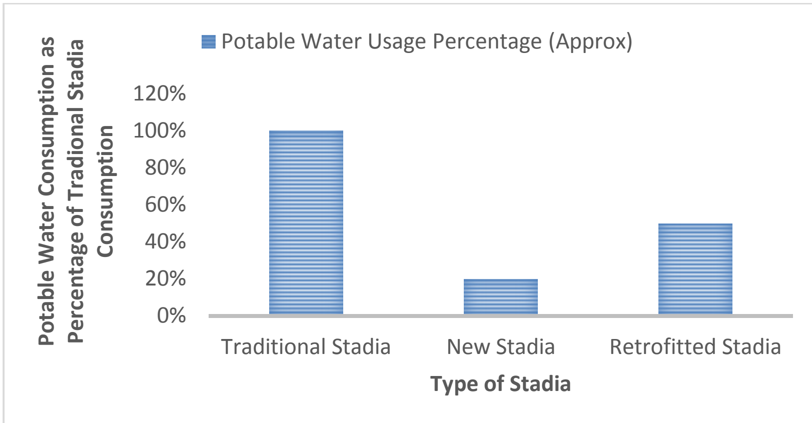

Figure 5: Comparison of Potable Water Usage for Traditional and Non-Traditional Stadia

New sustainable stadia (such as Levi's Stadium) can use 80% less potable water when compared to traditionally built stadia (City of Santa Clara Water and Sewer Utilities 2009). Retrofitting a stadium to include high efficiency fixtures and rain water capturing, amongst other strategies, can lead to up to a 50% reduction of potable water use. These savings have been found in Stadia such as Lincoln Financial Field, AT&T Park, Nationals Park, and more (Greener Building > LEED n.d.).

3.2.1: Water Efficiency and Reduction Opportunities for New Stadia

Depending on the geographical location of the stadium, many different water retention and limited usage techniques can be used. In areas of low water availability (arid and semi-arid climates) the main goal must be to limit water consumption at all cost. There will probably be limited availability for water collection (although simple gutter and cistern system can suffice); however there are ample opportunities for limiting water usage. In areas with more rain fall, water more sophisticated water retention techniques should be used. The stadium should be capable of collecting and reusing the rain water for a majority of its non-potable water usage.

No matter the geographic location of the stadium, non-potable water should be used to the highest extent possible. This includes toilet flushing, irrigation, and certain kitchen uses. In all sport stadia the toilets should be low flow (0.8 gallons per flush vs 1.6 gallons per flush) and the urinals should be 0.125 gallons per flush. The advances in high efficiency plumbing now make it possible to use more than 50% less water for sanitary needs. A waterless urinal can save 24,000 gallons of water per year alone (Miami Marlins, 2014). The sinks, showers, and kitchen equipment should all be water efficient. Furthermore, water from sinks and showers can be fed into the non-potable water system and reused time and again.

One of the largest single use consumers of water in sport stadia is most certainly field irrigation. Many playing surfaces can use up to 20,000 liters of water a day! A great solution would be to use grasses that work well in the particular climate, but often times the type of grass is dictated by the particular sport association. It is essential to not water the field during high sun times (middle of the day), however this is often not the case when there is an afternoon game. Also, it is imperative that stadia do not put an added pressure on the clean water systems and use only non-potable water for irrigation.

Water collection is a key sustainable feature for large and small sport stadia. A large stadium, such as the Miami Marlins Baseball Park, can receive up to 590 million gallons of water per year (USGS 2011). During the seasons of play, the stadia can use this water capture for field irrigation, toilet flushing, landscape irrigation, kitchen usage, etc. and still have enough water to give back to the community. A stadium can use anywhere form 14-51 million gallons of water during a year. Water catchment can provide the community with hundreds of millions of gallons of water a year. Local schools, government office building, low income residents, could all greatly benefit from freely collected (or less expensive) water use. This is an excellent way for the sport stadia to give back to the communities who help fund them.

Green roofs have many energy reduction qualities; however they also play a large part in water collection of a stadium. Green roof vegetation is designed in such a way that limits the water need to maintain the vegetation. A properly designed and installed green roof sustains off of the natural rainfall that falls on the building. This helps mitigate the storm water run-off tremendously. “Green roofs can reduce total annual run-off by as much as 60% - 79% and estimates based on 10% green roof coverage suggest that they can reduce overall regional runoff by 2.7%” (Oberndorfer 2007). Not all stadiums have opportunities for green roofs installed over the entire built area that would lead to such run-off reduction, but these numbers show the significant advantages of having green roofs in a project. Opportunities for green roofs may also exist in least expected areas; they can be used as covered parking, as architectural features, or in a variety of other ways.

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There are also many smaller innovative techniques to help reduce water consumption. The case study in section 2.3 illustrated some other strategies for water reduction, such as the use of ultra violet light in the concession areas to help reduce the buildup of grease and therefore reduce the amount of water needed to clean them. This may not sound like much but large sport stadia can have over 50 kitchens. Using coatings wherever possible to help reduce water usage is another excellent way to help minimize water demand.

3.2.2 Water Efficiency and Reduction Opportunities for Retrofitted Stadia

Establishing non-potable water systems can be costly for existing stadia, however many of the above strategies can be implemented to a lesser degree in existing stadia. For example, all stadia can still change to low flow/ high efficiency equipment in bathrooms and showers which can help drastically reduce the water usage of a stadium. No matter the age or condition of an existing stadium, there can be many different approaches to reducing potable and non-potable water usage. The existing stadia can also find individual innovative techniques to help minimize water demand, such as the example of ultra violet light in the concession areas. These individual touches can lead to a great amount of savings.

Most stadia have some sort of water deflection system to prevent flooding and to manage storm water. These systems can be tweaked to include water catchments or cisterns instead of being sent directly to sewer or other storm water management systems. By creating these rain water catchments the stadia could easily use this water for pitch irrigation, outside green space irrigation, or outside cleaning (walkways, walls, etc.). There are numerous uses for rainwater that can all be very useful to stadium operations. Similar to above, during the off season, this water can be used by the community to help limit potable water usage by the surrounding areas.

3.3 Material Reuse

Proper material use is critical in sustainable design. The earth's resources are limited and sport stadium must not ignore that fact. Reducing the amount of material used for stadium construction also has a tremendous positive impact on the environment. Minimizing materials will help reduce the energy needed to transport them and in turn help reduce the amount of greenhouse gases emitted during construction. It is also vitally important to use local materials to the upmost extent as this too helps reduce energy consumption and decrease greenhouse gas emissions. There are multiple strategies and concepts that can be used to help reduce the amount of virgin materials used for the building of a new stadium. Some these are discussed below.

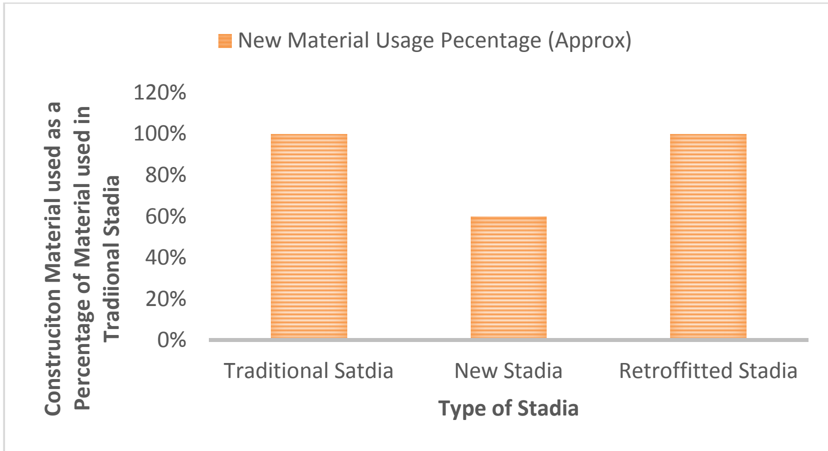

Figure 6: Comparison of Material Usage for Traditional and Non-Traditional Stadia

Material reuse is especially important in new stadia, as it can lead to a reduction of up to 40% virgin material use, as seen in London Olympic Stadium, (Populous 2012). Retrofitting a stadium has no distinct advantages as the virgin material has already been used in building construction. Traditional and non-traditional stadia can all benefit equally from limiting virgin material usage in operations.

3.3.1 Virgin Material Reduction Opportunities for New Stadia

It can be seen fairly often that stadium owners decide that it is easier or more suitable to their needs to build a new stadium, as opposed to retrofitting or upgrading the existing stadium, once their existing stadia are outdated. There are very few new teams or sports arising so most often existing stadia are replacements of old, outdated stadia. When this occurs, the architects and planners should be mindful of the availability of material reuse from the previous/existing stadia. When looking to demolish an existing stadium all possible reusable items should be carefully extracted and distributed between recycling, donations, and materials for the new stadium.

Many materials from existing stadia can be reused in new stadia as typically these new stadia are built very near the existing stadia (<5 miles). Materials for reuse include concrete and building materials, flooring, lights, stadium chairs, décor, etc. Instead of building a new stadium from scratch using previously used materials can save more than 30% of virgin material (Institution of Civil Engineers 2012). Concrete and building materials can be reused as structural elements in new stadia, gabions for support or décor, walls for retention ponds or other storm water retention systems, etc.

Specialized flooring, including but not limited to carpets, tiles, field turf or grass, green spaces outside the stadium, can be reused in a new stadium. It's important that designers and planners be mindful of this availability for reuse of these materials as many times existing stadia are imploded and there is little opportunity for reuse after that point. Any decorative or lightly worn carpet should look to be reused within the new stadium or donated to the community. This helps reduce the waste from old stadia and the amount of new material used in new stadia. Similarly, any decorative or usable tiles, from both flooring and walls, should look to be reused or donated/recycled. And the same can be said for green surfaces in the existing stadia. Turf or grasses used as playing surfaces from the existing stadia can be taken out and reused in the new stadia. This can also be said for high efficiency lighting, stadium lighting, stadium chairs, kitchen appliances etc. This is a great alternative to using virgin material and it helps reduce the transportation energy of new materials.

When all possible materials from previous stadia (if applicable) are exhausted, stadium owners and designers should still look to use recycled or post-consumer materials for the majority of stadium construction, decoration, etc. These items help reduce virgin material consumption and can add a very unique and distinctive decorative touch to a new stadium.

Another option that can help reduce material use is simply to design the stadium to use fewer materials. This can be seen as a main goal of the designers of the 2012 London Olympic Stadium. This helps reduce cost, energy consumption, and greenhouse gas emission. It takes a fair amount of ingenuity and simplicity to achieve this strategy properly, but it can be quite advantageous.

An additional approach to sustainable material application is to use rapidly replenishing and locally sourced materials. Rapidly replenishing materials include bamboo, cork, straw, cotton, wool, etc. These materials have a fast growth cycle that replenish quickly and therefore do not deplete the Earth's natural resources. Old growth woods and things of similar nature should be avoided as they take decades to replenish. Instead woods certified by the Forest Stewardship Council should be used. This mark ensures that the harvested woods meet the triple bottom line and are environmentally appropriate, socially beneficial, and economically viable (Forest Stewardship Council 2013). Using locally sourced materials is an excellent way to reduce energy consumption and greenhouse gas emissions. Locally sourced materials also help support and sustain the local economies of the area.

3.3.2 Virgin Material Reduction Opportunities for Retrofitted Stadia

Material reuse strategies are less available in existing structures, as all the material is already been purchased and in place. However, during large renovations many of the same strategies and concepts can be used. Suites can be renovated using post-consumer carpeting, fair trade forestry products, etc. Little by little stadia can make themselves more sustainable by incorporated more environmentally responsible materials.

3.4 New and Retrofitted Stadium Operations

Proper operations strategies are a great way for new and existing stadia to incorporate sustainable practices. Once a stadium is built, it is up to the operations team and managers to keep up the sustainable initiatives that were set forth during the design and construction phases. A sustainable stadium can only stay as such if the operations and maintenance of the stadium are up to the same standards established from day one. This section covers some operational strategies to help keep stadia sustainable long after they open. All the strategies listed below are available to stadia operators, some are more feasible than others, but with the right team, and the desire work with vendors and the community, all options are open.

3.4.1 Recycling/Composting Strategies for New and Retrofitted Stadia

Recycling and composting initiatives are excellent ways to reduce waste during games days. An average fan generates 2.44 pounds of waste per game day (Midpoint International 2013). In a stadium with a capacity of 50,000 spectators that is equal to 122,000 pounds of waste per game. However, proper recycling and composting methods can help reduce this number by 95% or more. The most important aspect of creating a successful recycling and composting program is to work with all the vendors to provide the most sustainable products possible. Creating RFP’s that ensure that the vendors list all possible products and their availability to be recycled/composted is a critical first step in developing a successful recycling and composting program at a stadium.

Major sports teams are large consumers of everything from plastic-ware to napkins to cans and bottles to food packaging and more. Contracts for these services can be in the millions of dollars annually, therefore the sports teams have the right (and obligation) to tell the vendors they want more sustainable options, or decide to go with a more sustainable vendor. This is the beauty of having the upper hand, the stadium operations manager can choose to only source sustainable products from their vendors.

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The goal of a successful recycling and composting program should be to only purchase items that can be recycled or composted after use, including items already marked as post-consumer products. This is the most important step to creating a successful recycling/composting program at the stadium. Without acquiring these items, only a small percentage of material used during a game day will be recycled or composted and the rest will end up in landfills. Items such as toilet paper, napkins, cans, bottles, plastic-ware, food wrappers or holders (hot dog, pretzel, chips, popcorn, cotton candy, burgers, etc.), material food arrives to the stadium in (cardboard boxes, plastic wrapping, etc.), game day brochures, etc. can all be recycled or composted when properly acquired.

Food waste is another issue during games days. Thousands of pounds of food are prepared for single game. While much of this food gets eaten during the game, there are still scraps from kitchens and left over food that needs to be accounted for. Every kitchen or concession stand should have a composting bin to throw out any food scraps (banana peels, onion skin, egg shells, animal bones or fats, etc.) that are not needed. This can save hundreds of pounds of food from ending up as waste in landfills and can instead be sent to local farms to serve as compost. Past examples have shown that farmers or other companies are willing to come to the stadium after games to pick up compost, so the effort needed by the stadium to rid themselves of extra food waste is quite small. Also included in food waste is used cooking oil. This cooking oil can be used to fuel biodiesel vehicles, preferably those used for landscaping in and around the stadium. In just one year, over 7,000 gallons of biofuel can be produced from excess cooking oil. This is equivalent to removing over 129,000 pounds of CO_2 from the air (MLB 2014).

Another option that applies to cooked, unsold food is to donate them to local food shelters and charities in the area. Programs such as Rock and Wrap It Up! help large events send their excess cooked food to the community that needs them. In just one month a stadium could help send 4,500 lbs. of food to the community instead of that food going to landfills or composting. Additionally, a great option to reduce the amount of plastic bottles is to use soda and water fountains instead of selling by the bottle. Stadium concessions can offer refills at a discounted price to entice users to keep using the same cup. Furthermore water fountains should be easily accessible and provide water at an appropriate temperature to help entice fans to use them and avoid purchasing an excess amount of plastic bottles.

3.4.2 Incentives and Other Sustainability Approaches for New and Retrofitted Stadia

There are a number of other food related incentives that can help make a stadium more sustainable. Firstly and most importantly stadia should attempt to source food from local vendors to help reduce energy usage and greenhouse gas emission and help support the local economies. This is especially true for healthy options such as fruit and vegetables. These foods are best served fresh and would provide a benefit to the community to source these foods locally and offer them at games in addition to typical unhealthy concession food. Providing pesticide free or non-GMO foods is also an excellent way of providing healthy and sustainable alternatives to for the spectators.

Other innovative approach to providing sustainable operations of a stadium is to offer sustainably harvested and locally sourced clothing. During an average game a stadium can employ from 3,000 to 5,000 employees. Sourcing this clothing locally can help reduce greenhouse gas emissions and support the local economy as well. It's a simple change that can go a long way to create proper examples of environmental stewardship.

Creating incentives to help and motivate the community is essential to maintaining sustainable operational practices. These incentives could include reduced or free tickets to spectators who bike, or use other alternative means of transportation, to the stadium. No matter how sustainable a stadium is designed, built, and operated, thousands of cars driving to the stadium are going to have a monumental negative impact on the environment. Another possible incentive is to provide free or priority parking to carpoolers. The stadium operation can even help set up carpooling or shuttle options to and from the stadium.

There are many other innovative approaches and incentives that can help create and develop sustainable practices within the stadium operation. These can be strategies can be implemented by new and existing stadium alike. The Miami Marlins showed such creativity when giving away free tickets for fans that brought in used electronics for recycling. These approaches help educate the community and show the stadium's dedication to environmental stewardship. Another excellent way to encourage fans and the community to learn about sustainability initiatives is to provide sustainability tours of stadium. Giving fans, students, or other members of the community the ability to go behind the scenes and see what makes a particular stadium sustainable is a fantastic way to teach the community about sustainability and encouraging them to take part as well.

4. Conclusions

Sport stadia have come a long way since the times of ancient Greece and Rome. Modern stadia have evolved to meet the comfort, safety, and entertainment needs of the latest generation, while at the same time are becoming increasingly aware of environmental stewardship and proper sustainable design practices. Using the proposed sustainable strategies, stadia stand to be critical pieces of the infrastructure for the community. They can be providers of electricity (potential of providing over 30,000 MWhr/year) and water (potential of providing 250,000 gallons of water per year), along with a source of education for environmental stewardship. All the approaches demonstrated in this paper are proposed to achieve optimum sustainable stadia. It is difficult to generally give emphasis to a particular strategy than the other due to the various factors that influence stadia design and operation. Simulation studies should yield the right strategies for the location and function of the particular stadium.

Even though a number of stadia have recently implemented successful sustainably design, there are still some concepts and strategies that have been used seldom or not at all in sustainable stadia. Onsite renewable energy from wind and biomass has little been explored. These renewable energy sources can have an ROI of as little as seven years, which is minimal in the life of a sport stadium. Equally solar panel use as a majority of covered parking, which could create excess energy for the building, is still an unused strategy. Green roofs and walls are a great way to reduce cooling needs (up to 5%) and subsequently greenhouse gas emissions, but these strategies are still not often used by sustainable stadia. Water efficiency measures should be standard in new stadia, with the ultimate goal being as little potable water usage as possible. Sport stadium are giant buildings with a large area. All the water that falls within the grounds of the stadium should be captured and re-used, either for the stadium or for the community. There is still a lack in rain water collection from major sport stadia.

Material reuse is another section of sustainable stadium design which can have an enormous impact on the environment. Material reuse needs be planned from the beginning of the design phase. This is particularly true since from the ground breaking of a stadium there is the opportunity to minimize waste and to reuse existing materials. Material reuse can also be found in the lighting, carpets and other flooring, walls, décor, etc. of a stadium. Additionally, stadia should look to incorporate rapidly renewable resources to the largest extent possible. Recycling and composting plans are essential in maintaining a sustainable stadium long after design and construction. An average game can generate 60 tons of waste, but through proper recycling and composting programs over 95% of this waste can be diverted from landfills. The best way to accomplish this is to work extensively with stadium vendors and ensure that the majority of products are recyclable or compostable. Lastly, stadium owners and operators can create other sustainability incentives to help motivate the community and spectators to follow in the stadium's sustainability footsteps. Incentives such as free or discounted tickets for alternative commuters or free tickets for bringing in e-waste have proved to be effective at encouraging fans to join the sustainability movement. Providing sustainability tours can also lead to increased fan knowledge and appreciation for the stadium, while educating the community on environmental stewardship.

This study gives a comprehensive list of options for future stadia to use in terms of sustainable strategies and concepts for sport stadia. While all the categories explored have clear environmental impacts, energy usage and the associated carbon offsets, along with water usage are of the extreme concerns to climate change and should be addressed thoroughly before project inception. There is quantifiable data that indicates the benefits of using these strategies and techniques and pushes the envelope to provide strategies that are not yet used in sport stadia. The goal of all sport stadia should be two-fold: to not impact the environment negatively and to give back to the community. Many stadia are achieving the first goal to some extents, but the consciousness of giving back to the community has not yet been achieved. This paper aims to enrich sport stadia design to reach the ultimate goal of providing to the community that houses and adores them.

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