University of Southern Queensland

Faculty of Health, Engineering & Sciences

Evolution of stadiums:

A study in the design and construction of ancient and modern stadia

A dissertation submitted by

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ABSTRACT

Stadia are an important structure within the urban landscape of a city. They offer a site for people with like-minded interests to gather and share an experience based on these mutual interests, and in turn provide economic and social benefits to the surrounding community. They are also a representation of advancements in technology and engineering that have occurred over history. Early stadia designs were constructed by the Ancient Greek and Roman societies, with a general focus on spectator capacities with little regard for the comfort or wellbeing of spectators. This focus has shifted over time, and evolution in the designs of such structures to meet the ever-changing demands and expectations of society has led to increasingly bolder and more unique stadia.

This dissertation will explore the history of stadia from the early structures in the ancient Greek and Roman empires through to modern day arenas. It will then investigate modern stadiums and analyse a number of factors that are taken into consideration when designing and constructing such a unique and defining building on the urban landscape. A case study of a new stadium to be built in the city of Perth in Western Australia will also be presented, with a focus on many of the decisions that have been made for the stadium and an analysis of the reasons behind these decisions. Upon reading this dissertation, readers should gain an understanding and insight into the history that direction that stadia design and construction has taken in the past, and hopefully develop an understanding of where the stadia design and construction aspects will head in the future.

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CERTIFICATION

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GLOSSARY OF TERMS

AFL – Australian Football League

BBC – British Broadcasting Corporation

CBD – Central Business District

DSR – Department of Sport and Recreation

EPA – Environmental Protection Authority

EPL – English Premier League

ETFE – Ethylene Tetrafluoroethylene

GDP – Gross Domestic Product

LED – Light-Emitting Diode

MCG – Melbourne Cricket Ground

MLB – Major League Baseball

NBA – National Basketball League

NFL – National Football League

NHL – National Hockey League

NRL – National Rugby League

PTFE – Polytetrafluoroethylene

PVC – Polyvinyl Chloride

VIP – Very Important Persons

WA – Western Australia

WAFC – West Australian Football Commission

1. Chapter One: Introduction

'The Colosseum remains one of the grandest and most spectacular engineering achievements of the ancient world. It would become the blueprint for stadia not just throughout the Roman empire, but throughout history.'

(National Geographic, 2007)

1.1 Outline of the study

The above statement attempts to portray the significance of the role that the Colosseum (also commonly referred to as the Flavian Amphitheatre) played in developing the designs and construction methodologies of modern stadia. It suggests the need to look to the past for inspiration in design and construction and to study these highlighted examples of engineering achievements in order to improve our own modern techniques and innovations.

1.2 Introduction

Whilst a stadium is often thought of simply as a venue to host sporting events, a look past this broad generalisation will uncover a much deeper meaning. It offers a venue for like-minded individuals in society to gather and share a common interest (usually in the form of sport or entertainment); however it can often also represent a microcosm of society. High value spectators and VIPs often have the best seats, views and levels of comfort within stadiums whilst those lower on the socio-economic ladder of society are usually in the upper tiers with lower comfort levels. A snapshot of the variety of spectators at a stadium will often provide a wide range of social classes.

Stadia are an important building block in society, offering entertainment or, in some form, an escape from the 'day-to-day life' of the average citizen. Their importance to society cannot be understated, which is why design and construction of these stadia is significant.

A poorly designed or constructed stadium can compromise safety to spectators, revenue streams to owners and the appeal to society. This can lead to urban degradation and anti-social areas; the opposite of community desires.

In order to properly design and construct a modern stadium, one must understand how stadia have evolved over the years and the reasons for changes that have occurred over time. Once this history has been examined, a greater understanding of modern stadium innovations can be appreciated and new & future stadia will ultimately benefit from better overall design and functionality.

1.3 Need for research

Stadia are by definition designed to accommodate thousands of people in one place to view and experience an event. Inherent problems are associated with the gathering of such large numbers of people and while solutions have been developed, the ever changing nature of the society that encompasses them requires evolution in the stadia themselves.

Whilst today's stadiums are being designed and constructed with extremely high standards and reviews, this was not always the case. Historically, stadia design in general has been described as lacking or poor, with many example of this all over the world (Sheard, 2008). As McCormack & Hove (1997) mentions, these inadequacies in design and construction are due to improper designs, unforeseen circumstances or incompetency on the part of the designers, engineers and builders associated with the project.

A proper working appreciation and understanding of past stadia is required for modern stadia design, so that one can approach this in a logical fashion and to understand historical problems that have been identified and rectified through the evolutionary design and construction process. Through this understanding of historical stadia, the reader can also better understand the new direction that stadia design and construction is heading in the future.

1.4 Research Aims and Objectives

This research is comprised of examining the stadia of the past, highlighting the associated problems that were identified with these stadia and the ways in which these problems were solved through natural and evolutionary design and construction changes.

The aim of this research project is to investigate the ancient and modern methodologies of stadium design and construction and discuss the evolutionary changes that have occurred over time as well as the reasons for such changes. Comparisons will be made between ancient stadia such as the Roman Colosseum and modern stadia (for example, Allianz Arena in Munich, Germany or the Beijing National Stadium in China). This will attempt to highlight how evolutionary changes in the design and construction processes have benefitted the way in which a stadium ultimately functions and services the community.

Upon reading this research project, the reader should have an understanding of the way in which stadia have evolved over time, gain an insight into modern stadia design factors and innovations, and an understanding of where these design and construction aspects are likely to head in the future. Application of some of these design and construction innovations will also be explored in a case study of a new stadium to be constructed in Perth, Western Australia. The ultimate aim is to provide a base of understanding for the reader in terms of stadia design and construction so that the reader can draw further conclusions themselves on where evolutionary changes could take stadia in the future, as well as highlighting issues that should be considered in new stadia.

The research project will primarily be a desktop study of stadia design, construction and evolution. However, a case study on a new stadium in Perth, Western Australia (projected to be completed in 2018) will also be undertaken to examine how evolutionary changes can be implemented and how they have will affect the design theologies in the present day.

This case study will involve review of available literature, from media articles to official releases of project plans, briefs and requests for tender by the Department of Sport and Recreation (the arm of the Government of Western Australia responsible for the project).

1.5 Research Project Methodology

The methodology of the research project is a theoretical analysis, partly in due to the broad topic chosen for the project, as well as accessibility to some of the research aspects (for example, buildings and structures such as the Colosseum that existed only in the past, or in cities in various locations around the world such as Allianz Arena in Munich, Germany). It is proposed that the research will be conducted in parts followed by analysis and documentation of the research before progressing with the next part of the research project in order ensure a high level of detail and technical ability.

Being a desktop study, the required resources are limited in that the major resources required will be the literature from various sources such as the USQ Library, analytical and language skills, and documentation software package facilities (such as a computer, internet access, Microsoft Office). Further resources will be required for the case study focus, however access to these resources (old and dated newspaper articled) have already been sourced prior to the start of the project, due to an interest taken in the project purely from a personal point of view.

1.6 Structure of this dissertation

The format of the research project is presented as follows. Chapter One briefly describes the outline of the research project and gives an introduction to the research, the need for the research and the ultimate goals of the research project.

Chapter Two undertakes a literature review of relevant sources and knowledge bases on the subject of stadia evolution in terms of design and construction.

Chapter Three will explore the origin of stadia, from the early Greek stadiums to the Roman structures that can still be seen today. Construction methods will be analysed, as many of these methods (such as Roman concreting) paved the way for concrete structures that we see in modern stadia today.

Chapter Four will examine the stadia after the ancient eras; from the 5th century to the 19th century when the revival of the modern Olympic Games in Athens in 1986 provided a catalyst for modern stadia.

Chapter Five will review modern stadia and examine how evolution of design have led to some of the most technologically advanced and unique innovations seen in stadia today. It will also examine the current focus of stadia design and construction, in relation to energy efficiency and environmentally friendly and sustainable construction techniques and design quirks. A number of innovative modern stadia will also be examined, to understand how they are developing new stadia based on the theories that have evolved over time.

Chapter Six is a case study of the new Perth Stadium to be built within the next 5 years. This will analyse the needs of a new stadium for the city, and how engineering can help to achieve these goals. It will also analyse the needs of the stadium, and explore the initial site considerations for the stadium and provide an overview of the features and drawbacks of the stadium.

Chapter Seven will conclude the research project, offering the reader a discussion of the research in a final manner. It will discuss the implications of this research project as well as its future application to stadia design and construction for the present and future, and suggest further research in design and construction methodologies that will improve the quality of stadia.

Chapter Seven will also offer a perspective of the direction of stadia evolution in the future, and the potential focus of the stadia design and construction fields in years to come.

1.7 Conclusion

This dissertation aims to provide the reader with knowledge on the history and evolution of stadia as well as an understanding of the future direction of stadium design. The research is expected to result in a heightened understanding of stadia which in turn will lead to better design and construction practices and ways of thinking.

A review of literature for this research will identify the position and tone of various sources, and will analyse the literature for the suitability purposes of this research project. This literature review will provide a critique of the information in the context of the scope of this research project and will analyse the views of the arguments presented.

2. Chapter Two: Literature review

2.1 Introduction

There are a number of literature sources detailing stadium design and construction, and the evolution of such factors throughout history that are readily available. However, not all sources agree with one another on some facts or points of view, and therefore it is imperative that a literature review be conducted to analyse any points of contention and comments necessary on the arguments presented.

There is also a distinct lack of literature that covers the span of research that will be investigated in this dissertation. There are multiple sources for aspects of the research presented here, such as ancient stadia, modern stadia and design guides, however there is no single point of reference related to the history and evolution of stadia design and construction throughout history. This research project will attempt to rectify that and present a paper that enables the reader to understand the history of stadia and gain an insight into the future of the industry.

2.2 Literature review

2.2.1 Ancient Stadia

The influence of early stadia on modern day stadia structures as a whole was enormous. As National Geographic (2007) implies, it was these early structures that were the foundation for many of the current stadia design and construction theories and methodologies.

According to Hirst (2013) and Olympia Greece (2009), the first Olympic Games were based on a festival of athletics held at the stadium in the ancient Greek city of Olympia from 776 BC. Greeka (2013) describes the original stadium as a 20,000 capacity arena constructed in the slopes of Mount Cronion, where the majority of seats were made of mud, with only a select few seats crafted to a higher level of detail and comfort for officials and VIPs.

Whilst the Stadium at Olympia is often credited as the first stadium, the original Panathenaic Stadium (built in 338BC) provided the first concept of a spectator-oriented stadium (Hellenic Olympic Committee, 2011). Spampinato (2012) does begin to examine the way the designs evolved, from the initial Greek amphitheatres built in excavated hillsides such as the original Panathenaic Stadium, but does not elaborate to a large extent. The Hellenic Olympic Committee (2011) details the initial specifics of the Panathenaic Stadium construction in both its original (ancient) form, its revival for the first modern Olympic Games in 1896 and its renovation for the 2004 Olympic Games in Athens.

This progression from the first stadium to a spectator-oriented stadium highlights the evolution of stadia design in its early iterations, as the focus of the design of such a stadium was placed on spectators and viewing areas rather than the athletics track itself (as was the case with the Stadium at Olympia).

Whilst the Ancient Greeks can be credited with the invention of stadia, it was the Ancient Romans that developed the stadia further with a further focus on spectator viewing and accessibility (Mezher, 2002). Yaroni (2012) discusses how the Romans initially employed design and construction methodologies learnt from the Greeks, and the first Roman stadiums were more-so amphitheatre in nature as gladiator battles took place in the centre of the Roman Forum, surrounded by temporary wooden stands. As the gladiator battles became more popular in society with citizens clamouring for views of the spectacle, the need for larger arenas became apparent. The size requirements became greater and greater until areas excavated in hillsides were no longer suitable, and the stadia evolved from a hillside viewing platform into amphitheatres with above-ground seating constructed of timber (initially) and then evolving to the use of Roman concrete in construction in later years for durability factors (Yaroni, 2012).

The use of Roman concrete in stadia such as the Colosseum evolved from a need for higher durability in structures against the elements such as wind, rain and fire that timber could not provide (Wayman, 2011). Whilst it is not in use in modern stadia, it is an ideal example of how design and construction of stadia evolved over time to meet different needs and focuses, and how these ancient stadia have influenced modern stadia design and construction. While National Geographic (2007) does highlight the concept of the Colosseum heavily influencing modern stadia design, it does not go into detail of how this occurred with examples or further research, but rather simply raises the idea during its concluding stages. Sheard (2005) does mention that the precedents for modern stadia can be found in ancient Greece and Rome, and does delve into an explanation of this to a degree.

Roman Colosseum (2012) and National Geographic (2007) both agree that the Colosseum was used steadily and often for two to three centuries since its completion in 80AD, however sometime in the III Century AD or IV Century AD this began to decline.

2.2.2 Stadia evolution

Spampinato (2012) reports that during the IV century AD, the importance placed on sports and sports practises was considerably reduced to a point where it was deemed unimportant in society, ultimately resulting in the development of sports facilities such as stadiums stagnating. Both Spampinato (2012) and Roman Colosseum (2012) suggest that the increased importance placed on religion (and more specifically Christianity) led to the admonishment of sports in public life. Sheard (2005) also presents this view, and mentions that no significant stadia were built for about 1,500 years.

Yaroni (2012) states that it was not until the Renaissance Era around the 14^{th} century that sports participation and popularity was restored in public life. She presents the idea that no permanent structures were erected as was the case in the earlier Greek and Roman eras, but rather temporary stages and spectator areas were constructed primarily from timber

The Hellenic Olympic Committee (2012) offers that it was not until the revival of the Olympic games (and the first modern Olympic games) in 1896 that permanent stadiums as we know them today would begin to be constructed again, however Terpstra (2012) notes that Bramall Lane near Sheffield, England in the first and oldest stadium of the modern era. Given this, one would be inclined to believe Terpstra (2012) given that other sources attempt to verify this claim.

2.2.3 Modern Stadia

Sheard (2005) states that there are five 'generations' of modern stadia that can be classified, each marking the development of a new type in the evolutionary process. He defines these generations as:

- First generation — emphasis on accommodating large numbers of spectators.
- Second generation — increasing spectator comfort and improving support facilities.
- Third generation — the family stadium, with a focus on safety and reducing anti-social behaviours.
- Fourth generation — multi-functional stadiums, funded by corporate sponsorship and media.
- Fifth generation — catalyst for urban regeneration.

Culley & Pascoe (2005, p. xi) also agree with this statement to an extent, in that 'more recently stadia have been evolving from one-sport stadia to multi-use venues' reflects the ideology that there is still evolutionary progress in what can be termed as 'modern stadia'.

Sheard (2005) goes on to say that whilst modern stadia can be theorised as five generations, the distinction between these is not black and white, as there is substantial overlap between these generations, and some stadia in existence hug these generational boundaries.

2.2.3.1 First Generation Modern Stadia

Thompson, Tolloczko & Clarke (2000) examine the first three generations of modern stadia to a point. First generation stadia had an emphasis on spectator numbers as ticketing with the key to financial success for such stadia. Sheard (2005) adds that the first generation of stadia placed an emphasis of accommodating large numbers of spectators, at a cost of quality and comfort of the facilities of the stadia. In Australia these first generation stadia consisted mainly of grass hills or embankments for spectators with little to no consideration for spectator comforts. These first generation stadia that were essentially 'bowls' for large numbers of spectators were the standard until stadia evolved into its second generation with the invention of television.

When the revolution of television was invented in the 1930s and 1940s, the need for spectators to be physically present at stadia to witness an event reduced. To compete with this and to bring in spectators, the focus of the stadia shifted slightly to attract an audience to the stadia with a greater emphasis on facilities and comfort for spectators. This focus on comfort also led to a greater level of safety incorporated into these new designs for second-generation stadia.

Whilst the main objective of first-generation stadia was to get as many spectators as possible for ticket sale revenue, the objective of second generation stadia was to generate a higher spend per spectator at the event, which could in effect offset the lower spectator numbers and ticket sales at events due to the impact of television broadcasts.

2.2.3.2 Second Generation Modern Stadia

The main catalyst for this second generational evolution was the invention and eventual broadcast of sporting events from stadia on television. This meant that patrons no longer needed to physically attend a match to view it and follow their team's performances on the pitch.

Sheard (2005) highlights the second generation of stadia as being responsible for a focus on events taking place in spite of adverse weather conditions. This led to floodlight installations at stadia to ensure that night events could be staged and broadcast on television, and in the 1950s under-soil heating was introduced to sport stadiums in colder climates such as cities across Europe.

Second-generation of stadia also paved the way for enclosures for stadia. The Astrodome in Houston, Texas (constructed in 1965) was the first fully air-conditioned enclosed sporting stadium in the world. This occurred due to the renewed focus on spectator comfort and facilities due to the nature of the stadia evolution, and also led to innovations such as the use of artificial grass as the pitch.

2.2.3.3 Third Generation Modern Stadia

Third generation stadia can be described as those stadia that were designed and constructed with a focus on family-friendly environments and family entertainment, to compete with the likes of family theme parks such as Disneyland (Sheard, 2005). During the early years of Disneyland (constructed in 1955) sports and events at stadia were male-dominated activities and tended to exclude families and females.

As part of this family focus, safety became a point of contention and emphasis for stadium design. Spampinato (2012) reports that a series of disasters at stadia in the United Kingdom that caused the deaths of hundreds of spectators. This reaffirmed the ideal held by many that sports stadia were not venues for families. The fallout from the disasters led to safety regulations and measures adopted by governments to ensure safety became a top priority for stadia. The main recommendation from these safety reforms in the United Kingdom was that stadia did away with concourses and became all-seater facilities. These reforms were soon adopted by many European stadia, and subsequently were undertaken by countries all around the world.

The overhaul of stadia to be constructed an all-seater arenas meant that the facilities at these stadia were far more accessible, safe and comfortable and were by extension more appealing for a wider and more diverse range of spectators. A focus was also placed on business initiatives within the stadia, and this led to the construction of museums, merchandising outlets, guided tours and restaurants within the stadia that appealed to families and the wider public as a whole.

Sheard (2005) also mentions that there are still many examples of second and third generation stadia today, though mainly in 'poorer' countries with lower social-economic status that may not be able to upgrade or develop modern stadia to a newer level such as fourth or fifth generation stadia due to the high costs involved. However, the literature from Sheard (2005) does not elaborate on these examples.

2.2.3.4 Fourth Generation Modern Stadia

Whilst the revolution of television was responsible for evolutionary design and construction changes in second generation stadia, the revenue generated by television broadcasts of sporting events was the catalyst for further evolutionary design changes.

Thompson, Tolloczko & Clarke (2000, p. xxi) offers the view that 'the aim of the fourth generation stadium is to offer information equal to professional broadcasts at facilities with are as safe and comfortable as our own homes' while Sheard (2005, p. 115) states that the Fourth Generation stadium is 'a direct result of Satellite TV'. Sheard (2005) goes on to clarify this, in that satellite television has emphasised stadia at the setting or backdrop to the televised performance of the event, and optimum lighting and acoustic levers are required for better broadcasts. As such, stadia design is now as focused on lighting conditions, acoustic considerations and appearance on television as it is on spectator facilities, comfort and safety.

A push on the marketing and communication aspects of stadia is a direct result of this Satellite TV influence, and corporate boxes and hospitality areas for sponsors and associates are now a staple inclusion of modern Stadia.

This evolution iteration of stadia design & construction is a direct result of technological advancements in the field of communications such as digital television and the internet, and modern designs of stadia incorporate these and place a large importance on these in the design phases due to the revenue that this generates for the stadium.

A new focus of fourth-generations stadia was also on the multi-functional use aspects of stadia. Traditionally, stadiums are utilised once a week for a sporting event for a certain period of the year. At all other times, the stadium is under-utilised and does not bring in any significant revenue for the stadium owners. Sheard (2000) states that a new focus as part of this generational evolution was on maximising use between event days through revenue streams such as bars, restaurants and corporate facilities.

2.2.3.5 Fifth Generation Modern Stadia

The fifth (and current) generation of modern stadia employ all the benefits of the evolutionary changes from previous generations and utilise the latest technology to construct unique iconic stadia to aid in urban renewal.

Stadia now have the potential to 'shape new cities and regenerate decaying areas of old cities' (Sheard 2005, p. 116). Katzer (2010) explains this well, in that stadia or indeed entire arrangements of sports areas, facilities and landscapes serve as placed of social transformation that dissolve the boundaries between the events and its spectators, social classes or ethnic groups. Fifth generation stadia is all about using stadia at a catalyst to improve cities (Culf, 2005).

As the focus is now on urban renewal, designs and construction of stadia have evolved to meet the needs of this focus. New stadia are now not so much just a sports arena as it is an entire sporting precinct, with residential and commercial areas associated with such designs. Landscaping of the exterior surrounds is now also often incorporated into design as a component of this urban renewal.

According to Rizzo (2008), a key trailblazer of the urban development trend of stadia design in the United States of America was the city of Baltimore. Baltimore's professional baseball team was to relocate to a stadium further downtown in the city's Inner Harbour district. It was also the catalyst for the renewal of a blighted and underused area along the waterfront of the city. Upon the opening of the stadium in 1992, the stadium drew in millions of tourists annually to the waterfront retail complex, on the back of the anchor that was the construction of the new stadium (Rizzo, 2008).

2.2.3.6 Advancements in technology and unique stadia

These evolutionary changes of stadia have led to innovations in the ways that stadia are both designed and constructed.

Allianz Arena in Munich, Germany is an example of a fifth-generation stadium that has also implemented advancements in technology to construct a unique and world class stadium. Spampinato (2012) and Zeh (2010) both agree that the Allianz Arena is a great example of modern stadia and the benefits of design and technological evolution of stadia. This stadium was built in a run-down area for the 2006 FIFA World Cup, and is now host to German Football clubs Bayern Munich and TSV 1860 München.

Allianz Arena also employs ground breaking technology utilising ETFE panels on the exterior to provide a visually stunning effect of the stadium, utilising the ability to light up its exterior ETFE panels and change colour. This stadium is a primary example of the way in which stadia has benefitted from evolution in design and technology over the years.

The Beijing National Stadium, constructed for the 2008 Summer Olympic Games (often referred to as the 'Bird's Nest') is yet another example of innovation in stadium design and construction that is the direct result of evolution of stadia as well as technological advancements. Hong'e (2008) describes the stadium as utilising over 50 of the latest technological achievements, with the design and construction focus on the use of environmentally-friendly materials and clean energy. Hong'e does not elaborate on these innovations in his article; however Pilloton (2007) specifies that the stadium includes such environmentally friendly measures that include a rainwater collection system, translucent roof that enables sunlight to shine through for the grass in the stadium, as well as a natural and passive ventilation system.

Hong'e (2008) does however briefly discuss the steel structure façade of the stadium. A total of 150,000 tons of steel was been used in the construction of this stadium for both structural and aesthetic purposes, and such design and construction techniques would not have been possible without the advancements and evolutionary changes that stadia design have gone through in history.

Innovations in the design such as those mentioned at the Allianz Arena and the Beijing National Stadium could not have been possible without the architects and engineers having a working understanding of stadia history, how it has evolved and where the next phase of stadia design and construction is leading.

2.2.4 Case study: Perth Stadium

A case study of the new proposed stadium in Perth, Western Australia will be conducted as part of this dissertation. In a Project Definition Plan published by the Government of Western Australia (2012), the new stadium proposed will be an example of the fifth generation of modern stadia in that it will create a whole new urban precinct at the proposed location and will be a form of urban renewal for the area.

The literature released by the Government of Western Australia (2012) presents solid arguments for many of the proposed designs and it appears as though previous stadium evolutionary changes have been employed for the future stadium. The literature is suitable for the purposes of the case study, as it provides reasoning for some of the proposals as well as for the needs for the new stadium.

However the argument for the chosen new location over the present location is still debatable as prior evaluations had projected the costs for a stadium at the new location as higher than if a new stadium were to be built at the same location as the existing major stadium in Perth. The Department of Sport and Recreation (2012) believes that the new location for the stadium on the Burswood Peninsula is of greater benefit to the community as a whole, but the fact that it will be constructed nearby to the Crown Casino and Entertainment Complex makes this a point of contention.

It is also interesting to note that the literature in some ways contradicts itself, as a report published by the same government entity (Department of Sport and Recreation 2007) highlights the benefits of constructing a new stadium adjacent to the existing stadium, effectively in the same location, rather than in the recently chosen location of the Burswood Peninsula to the east of the Perth CBD. A change in the governing party of the Western Australian State Government led to a change in the decision as to where the new stadium should be constructed, amid much criticism from the local Perth population.

A new location would however enable the new stadium to assume some of the qualities that define a fifth generation modern stadium, in that it will promote a level of urban renewal in the area. The proposed location is currently an inner city area 2.5 km east of the Perth CBD with little urban activity, especially at night. It is home to a golf course and a tennis centre – hardly the ideal facilities for urban renewal and regeneration. The Department of Sport and Recreation (2012) proposes that the new stadium will not just consist of an arena but an entire sporting precinct that has the potential to encompass retail and commercial areas as well as an entertainment precinct, and this reflects the definition of a fifth generation stadia as proposed by Sheard (2000).

It is beneficial to highlight that as this project is still in the preliminary phase, most of the available literature is from the project team itself and thus skewed in a somewhat positive direction and gives the distinct sense of being 'pro-stadium'. News articles offer a reaction or public opinion in some cases such as Prestipino (2013) who discussed the closure of the public golf course to make way for the stadium; however these are few and far between and offer no real insight or position on the designs or construction of the new stadium. Thus it is imperative not to take the face value of the information provided by the literature source in the Department of Sport and Recreation document in respect to any opinion-based information, and to explore it further. General facts included in these published documents, such as in relation to characteristics of the new stadium, are generally correct and unbiased though as they are simply facts being presented.

2.2.5 Future Stadia

Whilst there is some literature on the future of stadia and the direction they are headed in, it is somewhat limited and restrained. This also verifies the need for the future study and further research into the field of stadia design and construction, as a new evolutionary phase of stadiums is seemingly imminent. Knight (2010) offers the view that the future of stadia is most likely geared towards the development portable and/or modular stadia. Panganiban (2012) agrees with this insight, stating that the common understanding among experts is that modular structures for stadiums is the new trend, and the initial effects can already be seen in stadia such as the 2012 London Olympic Stadium.

The common theory is that this trend will continue into the future, however the concept of a truly portable and modular stadium is yet to be fully realised, and is a glimpse of what the future holds for stadia design and construction. The increased focus on sustainability within such stadia will also be a challenge to ensure we are creating the best stadia possible for spectators and the environment alike.

2.3 Conclusion

The literature has a general consensus on many issues and presents logical arguments for their facts (or viewpoints in some cases). Many of these positions can be endorsed, though some literature contradicts other literature sources and it is up to the nature of the research to determine an accurate position.

Forthcoming chapters will present further research on some of the points raised in the literature review as well as providing the reader with the required knowledge of stadia throughout history, the evolution of the stadia and the forces and reasoning that is driving those evolutionary changes.

3. Chapter Three: Origin of stadiums

3.1 Introduction

A stadium can be defined as 'an enclosure that combines broad space for athletic games and other exhibitions with large seating capacity for spectators' (Encyclopædia Britannica 2013c). The word stadium is derived from the Greek unit of measurement called a 'stade' which was a distance (180-185 metres) in ancient Greek footraces. These footraces were exactly 1 stade in length, and the word 'stade' was used first to refer to the footrace, and then after time it became a colloquial term for the location that the race was run.

3.2 The First Stadiums

The first stadiums in history began to appear in conjunction with the 'stade' footraces. Speculation surrounds the exact date of the first stadia, but general consensus is that they originated sometime around 8th Century BC. It is generally acknowledged that the stadium built in 776B.C. in the ancient Greek city of Olympia is credited as the first stadium. The stadium was in the shape of an elongated 'U' or a horseshoe and was long and narrow to accommodate the 'stade' event, with the starting line at one end and the finish line at the other end. Alongside the track a stone stand was constructed as a separate area for judges (often referred to as the 'exedra').

Figure 3.1: Stadia at Olympia from NW perspective (Olympia Greece 2009)

Figure 3.1 provides a modern-day view of the Stadia at Olympia from a North-West Direction. In this figure, the 'stade' or track can be seen and is predominantly the focus in this stadium, with grass embankments surrounding this. During competition and events, these grass embankments would have been mud that had been formed or moulded in such a way as to provide seating for spectators. The stone stand, or exedra, for the judges can also be seen in Figure 3.1 in the middle of the stade length, providing an optimal viewing area for the judges. Marble slabs were also placed at both ends of the track, which symbolised the start and end points of the stade footrace events.

As the events became more popular, the embankments were modified so that the mud seating areas could accommodate more spectators. The stadium was estimated to hold up to 45,000 spectators at its maximum capacity (Spampinato 2012).

The popularity of the athletics rose around in the ancient Greek society, leading to stadiums being built in other cities of the empire. Along with these arenas for the 'stade' (footrace) events, new arenas called Hippodromes were constructed. These ancient Greek stadiums were designed for horse racing, or more predominantly chariot racing.

Figure 3.2: Present day site of the Hippodrome in the ancient Greek city of Aphrodisias (Sellies 2006)

Like the Stadia at Olympia, the locations of hippodromes were generally dictated by the terrain, and were dug into a hillside. The excavated materials were used to construct the embankments for spectators, with seating on the two opposite lengths of the track. It took the form of an elongated horseshoe, or 'U' shape, in that there were two long lengths with a square end and a semi-circular end (Encyclopædia Britannica 2013b).

Seating tiers occupied the perimeter of the straight lengths as well as around the curve at one end. At the opposite squared end, seating was usually reserved for dignitaries and VIPs. Sizes of hippodromes varied based on needs and size of events. Often as many as 10 chariots raced around the track, which produced the necessity for the track to be up to 120m wide and 210m long (Encyclopædia Britannica 2013b). However, the first hippodrome (also located in the same city as the first stadium, the ancient city of Olympia) is reported to have been 780 metres long and 320 metres wide (Vikatou 2012).

Figure 3.2 illustrates the Hippodrome at the ancient Greek city of Aphrodisias in its present day form. The elongated U-shape can be seen surrounded by seating tiers constructed from stone. It is rudimental and an early iteration of the hippodrome form, though this is one of the best preserved examples of an ancient stadium of this kind in the Mediterranean region.

3.3 Transition from Greece to Rome

Whilst it was the Greeks that pioneered the stadia ideology, it was the Roman civilisation that advanced the design and construction techniques and shaped the way that stadia was used. The Romans further advanced the ideas that the Greeks before them had introduced, and some of these design ideas and construction theories introduced by the Romans are still used today.

As the Roman Empire grew as a result of the Romans invading surrounding regions of the Mediterranean, they integrated various parts of the societies that they had invaded.

The Romans adopted the Greek Hippodrome structure into its society; however it was developed further by the Romans, and known as a Circus rather than a Hippodrome.

The Roman Circus was constructed in a similar fashion to the Greek Hippodrome, in that it was designed for equestrian events in an elongated 'U' shape. However, the Roman Circus enclosed the entire structure with spectator seating on all surrounds of the arena, whilst the Hippodrome was open at one end and not completely boxed in by spectator viewing areas.

The Romans had a focus on spectators and increasing the number of spectators at an event. The push was for greater spectator numbers that would translate to high volumes of ticket sales. Rather than relegating spectators to the natural slopes of the hills that surrounded the Circus (as was the case with the Hippodrome), the Romans built upwards and constructed spectator tiers, with the lower levels usually made out of stone, and upper seating tiers constructed to a certain height from wood.

Perhaps the best-known example of a Roman Circus is the Circus Maximus. The Circus Maximus was situated just near the Colosseum in Rome, and was the first of the Circus' in the Ancient Rome Empire. It was also the largest stadium in the whole empire, both in terms of spectator capacity and area. The permanent wooden stalls that surrounded the Circus Maximus were built in 329BC, and it is this point that is generally credited as the initial construction of the stadium. It was also at this point that wooden starting stalls for the chariots were constructed with gates, with up to twelve stalls built for chariot racing.

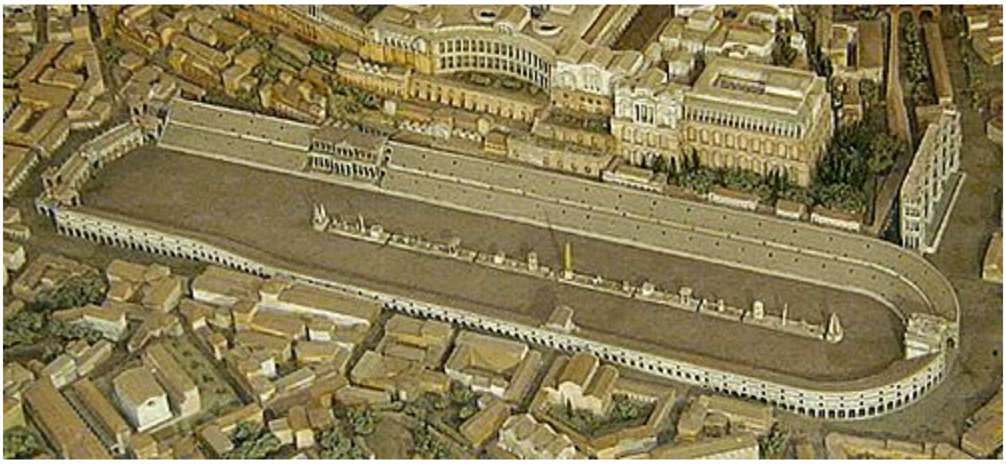

Figure 3.3: Scale model of the Circus Maximus (McManus 2003)

Julius Caesar further developed the Circus Maximus during his reign, ordering the extension of the seating tiers to run around the entire perimeter of the track and creating a processional entrance to the stadium. Julius Caesar constructed the stadium with an original capacity of an estimated 150,000 people, though it was later expanded to a capacity of 200,000-250,000 people (Encyclopædia Britannica 2013a) as the need for larger volumes of spectators dictated an increase to the overall capacity.

Figure 3.3 illustrates the Circus Maximus after the final modifications from Julius Caesar. The adjacent large buildings and houses convey the size and enormity of the stadium and its ability to hold a huge number of spectators.

A series of fires damaged the original circus over a period of time, and it was not until Emperor Trajan's dynasty that the entire Circus Maximus was rebuilt entirely from stone at around 100 AD and it gained its definitive form which was to remain unaltered until it began to fall into disrepair over time due to misuse and flood damage.

The original concept (or design) of the Circus Maximus was based on its most popular event at the time, chariot racing. The circus was constructed in the similar style of a Greek Hippodrome 'U' shape, with spectator banks lining every outer edge of the circus. However, other events were also hosted at the Circus Maximus, such as athletics, plays and recitals, gladiator contests, wild beast hunts and extravagant parades (Gill 2013). Due to the nature of the circus and the layout being less than ideal for many spectators within the Circus Maximus to gain a good vantage point of some of these events in action, the need arose for a more practical stadium for some of these events such as wild beast hunts and gladiator battles.

3.4 The Colosseum

In response to these needs and public pressure on the emperor regime, an amphitheatre was constructed to ease the unrest in the Roman Empire at the government.

Construction of the Colosseum began in 70 AD under the orders of Emperor Vespasian. Construction is reported to have taken 10 years. By the time the amphitheatre was finished and opened, Vespasian had since died and his son and successor Emperor Titus opened the stadium in 80 AD. This period of Ancient Rome encompassing the reigns of Vespasian (69 – 79 AD), and his two sons Titus (79 – 81 AD) and Domitian (81 – 96 AD) is known as the Flavian Dynasty. As the Colosseum is one of the structures constructed to celebrate the ascent of the Flavian dynasty, the Colosseum is also often referred to as the Flavian Amphitheatre.

The Colosseum was constructed just east of the Roman Forum, on the site of an artificial lake in the gardens of Nero's palace (Nero being Emperor Vespasian's predecessor). Originally, the site was a densely populated area, home to many citizens with houses and temples. During the Great Fire of Rome of 64 AD, about two thirds of the city was destroyed (Dando-Collins 2010). After the fire, Emperor Nero decreed that on the site an extravagantly large palace, the Domus Aurea (Golden House), would be built and would include vast gardens and lakes. The result of this was that many citizens were disposed of their former homes and land with nowhere to go, for the purpose of satisfying Nero's increasingly large ego. Political unrest began to rise within the Roman Empire, and ultimately lead to a period of turmoil for the empire and the eventual reported suicide of Nero in 68 AD. A power struggle ensued following Nero's death, resulting in the succession and demise of three emperors within one year, until Vespasian came to power in 69 AD based on the calls from the Roman government and the citizens.

Vespasian, wanting to demonstrate that the tyranny of the previous emperor was finished, decided to make a gesture to the people to attempt to gain popularity and settle some of the political unrest. This gesture was to build an amphitheatre – the Colosseum – on the site of Nero's extravagant palace, and was highlighted as a symbol of the new political order within the Empire (Pepe 1998).

The Flavian Amphitheatre, or the Colosseum as it is most commonly referred to, was opened by Emperor Titus in 80 AD, despite the fact that construction had not been fully completed. The amphitheatre towered over four stories and took 12 years for the entire construction. Once fully completed in 82 AD, the amphitheatre would stand about 50m high, with an exterior elliptical shape of 189m by 155m, and an elliptical arena at the centre of the amphitheatre measuring 88m by 55m (Yaroni 2012).

Unlike many structures of the era, the Colosseum had the majority of its features and details worked out even before construction began. The Roman engineers understood the need for appropriate foundations for a structure as massive as the Colosseum, and they designed it accordingly (though it could be argued that it was over-engineered, however upon evidence that it is still standing today and has stood the test of time shows that this was not necessarily a bad thing). An estimated 33,000 tons of soil was excavated from the bed of the lake for the structure until the excavations reached a firm layer of clay on which to lay the foundations. Once this layer of clay was reached, a section with a perimeter of 530m and depth of 6m was excavated and subsequently filled with Roman Concrete and Travertine Stone. A second 6m layer of concrete and stone was also poured on the first layer to create a 12m deep foundation. Next, brick walls 3m thick and 6m deep were constructed for reinforcement along the inside and outside of the foundation (Yaroni 2012). These enormous foundations were built with a number of goals in mind – take the massive loads from the Colosseum structure above it, and minimise the soil settlement that would have been associated with constructing the structure on the former site of a lake.

As the Colosseum was constructed on flat ground rather than dug into hillsides, the Roman architects needed a method to construct the necessary slopes in the structure for the seating tiers. The entire amphitheatre structure was based on the voussoir arch principle. The exterior or skeleton of the Colosseum consists of four storeys, with the first three stories consisting of 80 arches on the exterior to support the structure (National Geographic 2007). On the ground floor, each arch spans 4.2m wide and 7.05m high, whilst the arches on the upper floors are only 6.45m high (Pepe 1998). It is thought that the use of arches in this instance for the Colosseum was for a number of reasons, namely the proven strength of the arch structure in previous feats of Roman engineering (such as the aqueducts), the lesser requirement for building materials used in the construction of the Colosseum, as well as the functionality of using arches in the exterior façade. The 80 arches at ground level were used as entrances, with 76 regular entrances and four grand entrances that were generally used by VIPs. The use of every arch for an entrance (and in turn an exit) provided the ability for the stadium to be filled or evacuated quickly. As is with many modern stadiums, each arch was numbered to dictate an entrance number, as was each staircase. The Romans also pioneered the ticketing and seating system. Spectators at the Colosseum were given a ticket in the form of a clay tile with a number on it, which indicated the seat, section and row as well as the entrance gate number.

The fourth storey of the colosseum did not consist of arches, but rather was more solid with windows placed periodically around the perimeter and pilasters (slightly projecting columns) for aesthetics. At the top of this fourth storey, a canopy system made from material was implemented as a form of cover or roofing for spectators. This was the first type of roofing structure utilised in a stadium, and was constructed to improve the comfort of the spectators within the stadium.

Within the outer rings of 80 arches on each storey, the engineers constructed a further six concentric rings of arches internally for the spectators seats to be constructed on. The rings formed the base of the seating tiers within the Colosseum, which can be seen in Figure 3.4.

The Flavian Amphitheatre was constructed using a variety of materials. Travertine Stone was mined at a quarry 20km away at the nearby town of Tibur (now known as Tivoli), with a road built from the quarries to Rome for this purpose. It is estimated that over 100,000m^3 was used for the structure, with 45,000m^3 for the external façade alone (Pepe 1998). This stone was used for the main pillars, the ground floor of the building and the external wall, as well as within the extensive foundations of the structure. The travertine stone blocks on the building's façade were connected together not by cement or mortar, but by iron bars (that have since been removed).

The seating of the arena was constructed from marble in the lower levels for those citizens with a higher social standing, and timber in the upper levels for the poor and less important members of society. There was a certain hierarchy within the Colosseum at it provided a microcosm of the social standings within Rome itself. As Figure 3.4 shows, the most important of society such as the Senators, Knights and Noble Class of the Roman Empire were afforded the best seats in the arena whilst the poorer citizens, women and slaves were only able to sit in the upper tiers. The quality of the seating also varied with the importance of the citizens. Those in the lower tiers were provided large seats constructed from stone and marble, but those in the upper areas were only provided wooden benches, often steep or standing room only.

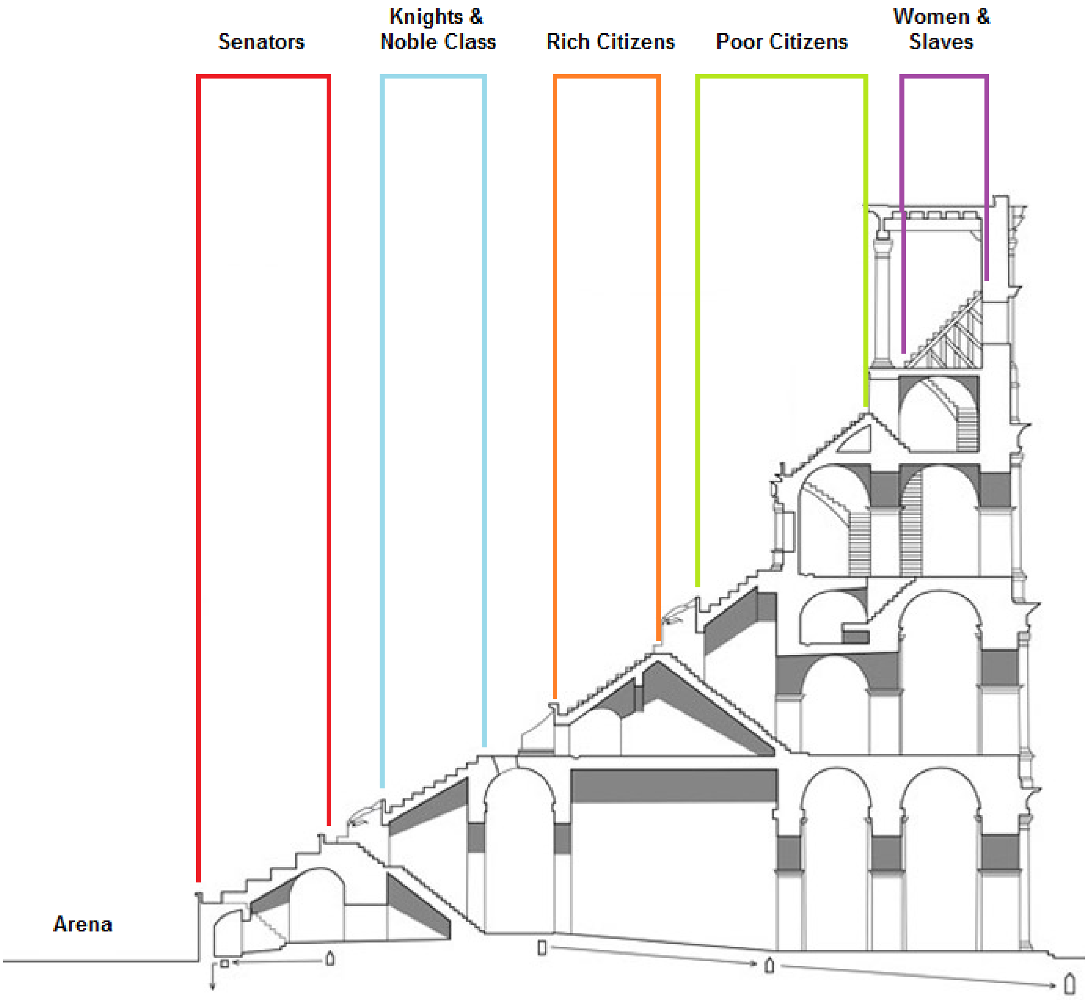

Figure 3.4: Cross section of the Colosseum, illustrating the seating hierarchy within the arena (Pepe 1998)

3.5 Roman Concrete

The Romans started utilising concrete in their structures over 2000 years ago; however the early Roman Concrete was not the same as modern concrete. Roman concrete was not made up of some of the easily accessible materials that are available today, and as such had a different formula and was as a result considerably weaker than concrete of today. It is estimated that Roman Concrete had about $1/10^{th}$ the strength of modern concrete (Wayman 2011), however it is seen to have incredibly durability over time as evident from structures such as the Colosseum.

Whilst modern concrete is a ratio of sand, water, aggregate and cement (usually lime based), Roman Concrete differs in a number of ways. Refined cement was not available; however volcanic ash was mined for the purposes of a construction material. A mixture of this volcanic ash with a lime paste (consisting of limestone burned to create a quicklime ash material and water) was used in conjunction with an aggregate such as brick to create a strong building material with incredible durability.

The earliest forms of Roman Concrete used volcanic ash from various deposits of ancient volcanic ash and activity from around the region. Eventually, it was discovered that the different sources of ash produced different strengths of concrete, and builders became more selective with the volcanic ash that was sourced for the use in their mortar mixes. This was around the time of the first Roman Emperor, Augustus in 27 BC. At this time, the Emperor initiated an extensive program within the city of Rome to repair old monuments as well as install new ones around the city. The builders began to only use volcanic ash from a deposit that they dubbed 'Pozzolane Rosse'. This volcanic ash deposit was the remnants of an eruption from a volcano roughly 450,000 years prior (Wayman 2011) in the Alban Hills, 19 kilometres southeast of Rome. The Roman builders favoured this deposit and used it almost exclusively as it proved to have a high durability, and this began what would become a standardisation of mortar mixes utilising the Pozzolane Rosse volcanic ash.

One of the greater advantages of Roman Concrete is its durability when exposed to salt water. It is widely speculated that the Colosseum was often the scene of extravagant naval battles, where the arena of the Colosseum was flooded with seawater and ships brought in for the spectacle. Despite this, the Colosseum is still standing in relatively good condition nearly 2,000 years after construction and is a testament to the durability of Roman concrete.

Modern day concrete on the other hand is created with Portland cement and has an average life of 50 years when exposed to sea water, after which it begins to erode. Further examples of the durability of the Roman concrete can be seen at many harbours where breakwaters constructed over 2000 years ago from Roman Concrete continue to survive despite years of being submerged by the Mediterranean Sea and the associated wave actions pounding against it. Descriptions from Vitruvius, an engineer for Emperor Augustus, and Pliny the Elder, that date back to the ancient era state that the volcanic ash from the Pozzuoli areas (that supplied the Pozzolane Rosse volcanic ash) is classified as the best for maritime purposes, or structures coming into regular contact with sea water (Preuss 2013).

New evidence from researchers has come to light, as stated by Warner (2013), for the reasons for the durability of this material, and its potential to be applied to modern concrete compositions. The apparent secret to this material its unique mineral formulation and production technique. For underwater structures, lime and volcanic ash were mixed with tuff (a rock consisting primarily of consolidated volcanic ash), and the mortar and tuff mixture was then packed into wooden formwork structures. Seawater was then applied, instantly triggering a hot chemical reaction that hydrated the lime by incorporating water molecules into its molecular structure, and subsequently reacted with the ash which cemented the entire mixture together. The binding properties of this mixture were very high, much higher than that of modern day Portland cement. Today's modern concrete lacks the volcanic ash component that essentially made up the Roman Concrete material, and lacks that binding property, which results in the weakening and cracking of modern concrete that is experienced in the modern age with the use of Portland Cement.

3.6 Roman Arches

The Romans heavily incorporated arches into their structures due to their proven construction stability and reliability. The Colosseum was designed to utilise the arch concept, and has become iconic for the stadium and the city as a whole.

Arches reportedly began appearing in Roman architecture as early as the 2nd Century B.C. It has been said that the Romans were not the inventors of this feat of structural engineering as there have been circular brick arches built that date back to around 1400 B.C. (Mezher 2002), however the systematic use of arches began with the Romans, who developed the designs and applied them to a wide range of structures.

The arch was adopted as a construction technique to allow for openings in walls, as well as for its structural purposes as a base element for vaults that were to be incorporated within the structure (a vault is a term that refers to a roof in the form of an arch or series of arches). Though the Romans had previous success with columns and lintels within their structures, their ambition gradually increased and bigger buildings were desired. The resultant structures required more and more columns and lintels to support the forces present, and this is turn presented problems for both engineering aspects as well as the aesthetics of the buildings. Therefore the Romans began to utilise the arch after gaining understanding of its behaviours through trial and error.

The most commonly used arch by the Romans was the Voussoir arch, which was semi-circular in nature and employed the use of a keystone in the arch. The voussoir arch is a structure that can span a large area whilst resolving forces into compressive stresses and eliminating tensile stresses. The forces are carried to the ground through to the base of the arch, however as the forces are carries to the ground, the forces will act on the base and push it outwards. As the height of the arch decreases, the outward thrust force increases.

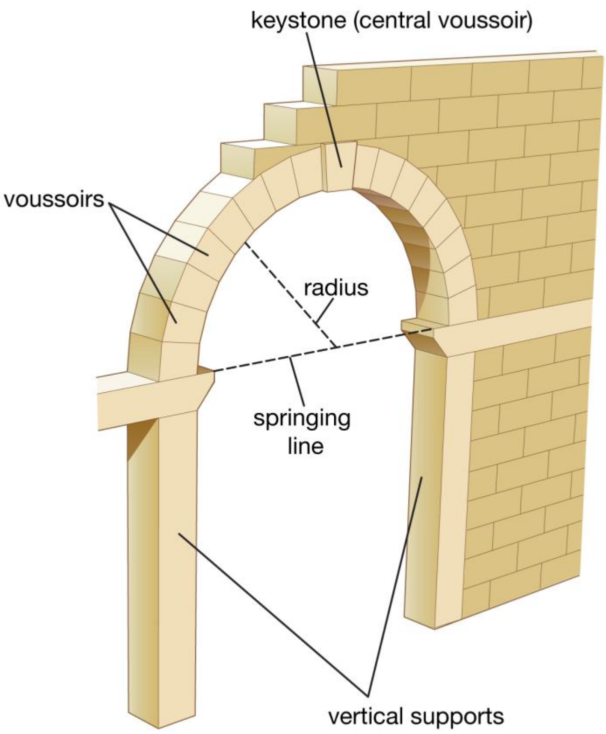

Figure 3.5: Diagram of the key components of a Voussoir Arch (Encyclopaedia Britannica 2012)

Figure 3.5 above demonstrates the principle of the arch. The two integral parts of the arch is the keystone and the springer. The keystone at the top of the arch (placed last in the construction) locks the arch into place and is the key to distributing the supporting loads as compressive stresses down to the base. The voussoirs are the other wedge-shaped elements of the arch that combine together to give it its strength and shape. The springer is the lowest voussoir element as the arch transitions from curved to the vertical support.

The forces from the arch were supported by transferring the forces down through the vertical supports, and created resultant outward forces on the vertical column of the arch. As a result, abutments or similar are required to support the horizontal thrust of the arches to ensure their stability.

Figure 3.6: Exterior of the Colosseum in Rome, Italy illustrating the arches used for support (Squires 2012)

The Romans solved this problem by creating a series of arches, and supporting an arch with another arch on each side that would counteract these outward forces that were present due to the nature of the arch. Figure 3.6 highlights this to full effect, as the first three stories of the Colosseum's façade were constructed from a series of arches that all balanced each other out and counteracted all opposing forces with opposite forces of the same magnitude. This was not the only example of the Romans using these arches in unison for force balancing and strength, as examples such as the aqueducts and parliamentary buildings also show.

3.7 Conclusion

Stadia have come a long way from their humble origins as simple grass fields surrounded by hills and embankments for spectators. They are a catalyst for the way that stadiums are both designed and function today, and many of these ancient and initial techniques or ideas are still in place today in some form or another. The ancient Roman Empire had a huge influence on modern day stadia, especially the way in which they operate, and this legacy will continue into the future through the evolution and redefining of many of these ideas first implemented by these stadium pioneers.

4. Chapter Four: Stadiums throughout the ages

4.1 Introduction

Early stadia in ancient Greece and Rome have played an important role in the design of modern stadia, as well as influencing stadiums in the centuries between then and now. However, societies in the middle ages did not generally have the organisation or resources of the Roman Empire. As such, large permanent stadia such as the Colosseum or the Circus Maximus were not the basis for stadia in medieval times or the Renaissance, and such large structures were non-existent during these periods. Instead, stadiums were built for purpose with far more limiting resources than in ancient times, and were of a more temporary or portable nature than some of the grand arenas seen in previous eras.

4.2 Centuries of suspension

Stadia and organised sporting events were popularised during the ancient Greek and Roman eras and a high significance was placed on these aspects of society. The Colosseum was used for events by the Romans for centuries since its inception, with the last gladiatorial games recorded in 438 A.D. (Pepe 1998), after which these gladiatorial games were abolished by Emperor Valentinian III.

With acts such as the abolishment of the gladiatorial games at the Colosseum, the importance placed on sports and events by society dwindled as priorities were reassessed over the world. This also coincided with the decline and fall of the Roman Empire in the 4^{th} – 5^{th} centuries AD, which heralded a new era in history.

After this period, the importance of Christianity and religion in these regions was heightened, and there was a shift in the integral components of society from stadia and sporting arenas to churches and cathedrals. Many of the ancient Greek and Roman sports structures were abandoned over time, with a number of those being converted by the people into markets and houses, or fully torn down to make way for new structures and for the building materials (Spampinato 2012).

4.3 Stadium Revival: Middle Ages & The Renaissance

After what is sometimes referred to as 'Centuries of suspension' of sporting cultures and games (Spampinato 2012), large organised sports practices were given a boost in the 10th century during the Middle Ages. Human and equestrian events, such as sword fighting and jousting, were reintroduced into the public domain. Gladiators of the ancient era were replaced by Knights who were the main spectacle; the heroes of the show.

The first recorded jousting tournament was in 1066 (Draak 2011), however the spectacle did not gain widespread popularity until around the 12th Century. Due to the nature of the sport, injuries and death were common, especially during the early years. King Henry II moved to ban the sport for fear of injuring or maiming too many knights from his army.

King Henry II's successor King Richard I reversed the ban once he ascended to the throne, and sought to organise the sport in the process. He incorporated a licensing system for the sport, so that not just anyone could take part as they were required to be registered under the King's regime.

By the end of the 13th Century, jousting tournaments (and some associated side events such as sword fighting) became incredibly popular. This led to reforms in the rules, with new guidelines aimed at reducing the potential for injury and death. It also led to standardisation of the jousting fields, in their length and structure.

To house these events, areas were set aside in open spaces within towns. They were often held on fields within close proximity to the castle of the monarchy. Whilst the Romans and Greeks built permanent monuments to stadiums in the form of stadiums and arenas from stone and concrete, the stadia used for these events in the Renaissance were of a far more temporary nature. Spectators would view the jousting and other events from improvised stands such as castle battlements that surrounded the field of play, or stand beside jousting fields behind makeshift wooden barriers. In larger towns or for bigger events, a grandstand was often constructed from wood, built a whole storey above the field of play (Alchin 2012). This wooden grandstand would house noble spectators, VIPs and ladies. In addition to these grandstands, bright round medieval tents were erected around the jousting tournament areas. These were known as Pavilions, and were of differing colours to house participants, officials and surgeons for the jousting tournament; an early form of team change rooms and areas that are incorporated in modern day stadia.

4.4 Other sports and events

Whilst jousting and equestrian events led to the revival of organised sports and sports stadia, over the years stadia were further developed to cater for a variety of different sports. Generally in the European and Mediterranean regions the main sport was football (soccer), or other similar organised team sports. These team sports increased in popularity, which led to the need for construction of new stadia to house these events and their adoring fans wanting to glimpse the action of their favourite teams and players.

Calcio Fiorentino (also known as Calcio Storico or its English translation 'Historic Football') is one such example that led to the development of stadia. Originating in the 16th Century in Florence, Italy, Calcio Fiorentino is a sport similar to modern day football. The game is played on a field of sand, with the objective to throw the ball into the netting at the opposing team's end of the field. The slight twist however was the violence and physical contact that was not only allowed but encouraged in the sport.

The pitch is the Piazza Santa Croce in Florence, Italy. It is here that teams would fight out for the honour of the title, watched on by hundreds of spectators. As it became more popular, it was apparent that the spectators required larger areas to view the action. Temporary wooden stands were constructed and erected on each of the four edges of the pitch (Dunant 2013). Figure 4.1 below depicts the early stadium arrangement that the Calcio Fiorentino was held in.

As the sport was not played year round, but generally only in a small period in the summer, the stadium's spectator seating was required to be temporary, so that the Piazza could be used at other times of the year for other purposes such as public meetings or gatherings. This is an early example of the utilisation of temporary spectator stands in stadia.

Figure 4.1: Illustration of the early iterations of Calcio Fiorentino (Harald Stjerna, circa 1688)

4.5 Rebirth of the modern Olympic Games

The ancient Greek Olympic Games were first recorded around 776 B.C., though speculation exists that by this time the Games were at least 500 years old (History.com, 2013). The games were banned in 393 A.D. by Emperor Theodosius I, due to their apparent pagan influences (Rosenberg 2000). With the beginning of the Renaissance and the Industrial Eras, organised sporting spectacles grew increasingly popular in the 18th and 19th Centuries. After a period of 1,500 years since the final ancient Olympic Games, the modern Olympic Games were reborn in Athens, Greece in 1896 with 280 athletes from 13 countries.

Athens was chosen as the location for the inaugural modern Olympic Games, and the track and field events were held at the Panathenaic Stadium. Originally constructed in 330 B.C. and used for the ancient Olympic Games, the Panathenaic Stadium was restored for these first modern Olympic Games in 1896 as the stadium had survived the test of time, albeit in a more dilapidated condition.

In its original form in the ancient Greek era, the Panathenaic Stadium was of a rectilinear shape. Spectators would sit on the earthen banks surrounding the arena, and later on wooden stands that had been constructed to allow greater capacity at the stadium.

Significant works were carried out to stadium under Emperor Herodes, changing the shape from its initial rectilinear form to a horseshoe shape and replacing much of the seating with marble, as well as creating statues and other features from marble. This refurbished stadium had a new capacity of 50,000 spectators (Hellenic Olympic Committee 2011).

Upon the selection of Athens as the host city for the 1896 Olympic Games, the remains of the ancient Panathenaic Stadium were excavated and the Stadium was restored again The stadium was reconstructed to reflect its initial form, and thus was again constructed from marble. The capacity was reportedly increased to 80,000 for these games, though the present capacity of this stadium is only around 50,000 (Spampinato 2012).

Since 1896, the Olympic Games have been held every four years (except for interruptions due to war) with a different host city selected for each event. Due to the popularity and prestige of the Games, cities would fight it out for the honour of hosting the Olympic Games even if they did not have adequate infrastructure at the time.

The revival of the modern Olympic Games is markedly a critical point in history for sports and stadia, as it led to the construction and development of sports stadia all over the world. Host cities that had won the right to host the Olympic Games needed to construct stadia in order to cater for the events and the spectators that would inevitably follow. As a result, stadia such as the Panathenaic Stadium and other ancient stadia formed the basis for design of new stadia to hold the Olympic Events.

The following Olympic Games in Paris in 1900 and St Louis in 1904 were deemed failures when compared to the success of the Games in Athens in 1896. The Olympic Games in Paris did not even have a stadium, and of all the 650 athletes at the St. Louis Olympic Games in 1904, only roughly 70 were from a country other than the host country (the United States of America). A second Olympic Games of sorts was held at Athens again in 1906 (though not officially recognised by the International Olympic Committee), and this seemed to spark public interest again and competitors from a host of different countries attended these Olympic Games.

Figure 4.2: Panathenaic Stadium in Athens, Greece (John 2006)

Figure 4.2 depicts the modern-day form of the Panathenaic Stadium in Athens, Greece. The stadium again underwent renovations for the 2004 Athens Olympic Games, where the stadium hosted the archery events as well as serving as the finish line for the Marathon event. Whilst the stadium has received upgrades, Figure 4.2 is an accurate depiction of the stadium utilised for the first modern Olympic Games in 1896 as the layout and structure of the stadium is essentially the same, though some of the fixtures and fittings within the stadium have since been refurbished.

4.6 White City Stadium

London was selected as the host of the 1908 Olympic Games, though it did not have the stadia structures at the time it was chosen as the host city. White City Stadium was constructed for the purpose of hosting the 1908 Olympics in London. The stadium had some initial influences of other stadia such as the Panathenaic Stadium due to the success of the first Olympic Games in Athens. However the designer of the stadium (engineer J. J. Webster) took this further, examining the needs and requirements for such an arena and innovating the design for these requirements. There was a greater degree of focus on accommodating spectators and larger capacities, and J. J. Webster took this into consideration.

White City Stadium was constructed so that almost the entire Olympic Games could be viewed from anywhere in the stadium, as depicted in Figure 4.3. By today's standards it would be considered crude and obsolete; however at the time of construction in 1908 it was hailed as a structure to behold. Unlike previous stadia, it was designed to hold a variety of events, as evident by the 536m running track, 600m cycle track and swimming and diving pool all incorporated within the field of play.

Figure 4.3: White City Stadium in London, England (BBC News 2012)

The materials used for the construction of White City Stadium were also of considerable difference to previous stadia. Whilst past stadia employed the use of stone, marble, travertine and timber, the main feature of White City Stadium was its steel frame structure. Steel was used for the seating tiers, as well as to support the simple roofs that spanned sections of the straight lengths of the spectator seats within the stadium (Yaroni 2012).

White City Stadium is often described as the precursor for the modern seated stadium. Indeed this stadium was a pioneer in the ideology of the seated stadium, however of its ultimate capacity of 150,000 spectators only 68,000 had seats, and of those only 17,000 of those seats were under the cover of the roofs along the straight lengths of the stadium (Yaroni 2012).

4.7 Five generations of modern stadia

White City Stadium can be highlighted as an example of a first generation stadium, due to its focus on high spectator numbers and the sporting arena itself, with little regard for actual comfort and experience of the spectators. The idea of these first generation stadia was that as long as a person could fit into a stadium and attend an event then they were a spectator, with little regard for their view of the event or the facilities within the stadium afforded to the spectator.

Though the Olympic Games gave rise to the use and requirements of stadia in the modern age, the increasing popularity of football within Great Britain led to more construction of stadia. Each football team had a home ground, and by extension needed a stadium to hold the spectators wanting to catch a glimpse of the action. A model for football stadia was developed in Great Britain, with rectilinear stands running parallel to the sides of the pitch, constructed usually of concrete. This model of football stadia was exported from Great Britain to the rest of Europe and eventually to South America, along with the passion for the game of football itself.

With the invention of television in the 1930s and 1940s, the ability for sporting events to be telecast to millions around the world became apparent. This meant that spectators no longer needed to travel to a stadium to view a sporting event, and could now do so within the comfort of their own home.

This led to two important evolutions in stadia design. The first was on the spectator experience. In order to continue to attract spectators to a ground to view a sporting event, new stadia began to be designed with a more spectator experience in mind. It led to improvements in facilities such as toilets as well as the inclusion of food and beverage facilities within that stadium itself. It also resulted in a greater push for roofs over stadiums, as the notoriously average weather of Great Britain had a tendency to provide less than ideal conditions for sitting outside and watching a sporting event.

The second important evolution that resulted from the television revolution was the design focus on providing a good experience for the home viewer as well. The result was stadiums constructed with artificial lighting, to ensure sporting events at night were possible. Stadiums today would not even be considered without some form of artificial lighting for night events and broadcasts.

While the focus from television turned to spectator comfort, it did not address the major issue of safety. It would not be until a series of unfortunate and catastrophic stadia events that stadia would evolve into the third generation. A series of fires in a number of stadiums utilising wooden stands, in conjunction with the rising sensation of public violence and hooliganism sparked calls for increased safety for patrons at sporting arenas. Stadium disasters that resulted in deaths of spectators were also prevalent, such as the Heysel Stadium disaster in Belgium in 1985 where 39 football spectators died. The final straw was the Hillsborough disaster of 15 April 1989 where 96 spectators were crushed to death and a further 766 people sustained injuries (BBC News 2009) after large crowds were allowed to enter one end of the ground, and led to the failure of the crushing barrier and caused spectators to fall on top of each other and crush them to death.

Key findings from an investigation into the Hillsborough disaster, titled the Taylor Report, mentioned that the key element of the disaster was the failure of police control. However, the Taylor Report also led to the removal of all standing terraces at major football stadiums across Great Britain. This advice would soon be followed by stadia all around the world, and stadia were redeveloped to be all-seater stadiums (Spampinato 2012). The Taylor Report became popular not only in Great Britain but over the whole world, and led to reforms in stadium design and construction that has greatly benefitted today’s new and modern stadiums.

New stadia in this third generation were developed with a distinct focus on safety and family-friendly environments. Violence and hooliganism turned off many of those wanting to take families to the football in Great Britain, and spectator numbers were down while crowd violence and anti-social behaviour went up. The focus on safety and family friendly environments to compete with the likes of Disneyland and other similar theme parks led to more comfortable and safe stadia which in turn attracted a more diverse crowd to the stadium.

It also resulted in development of better facilities for inclusion within the stadium. Museums, restaurants, guided tours, corporate boxes, merchandise and retail stores were all part of the evolution into the third generation of stadia, and also portrayed the stadium as a destination for the public seven days a week and not just for sporting events.

This third generation of stadia had a high commercial focus. These models proved very successful in their initial forms around the world, and new stadiums all began to capitalise from corporate sponsorship deals as well. Advancements in technology also furthered stadia development, as the invention of satellite television brought with it the demand for live sports broadcasts of a high quality, no matter where in the world the spectator was watching from.

Increased revenue brought in by broadcast rights led to an increase in the marketing and communication aspects of stadia. Requirements for high quality television broadcasting environments also created a focus on stadia lighting, acoustics, advertising and general appearance on television.

A sporting event broadcast on television is far more appealing when there is an atmosphere created by the spectators at the event as well, and this also led to higher quality spectator facilities and comforts. Televisions began to be installed in some sections, and in newer stadia seats in VIP sections would have their own personal television screens built into the seats (such as those at Docklands Stadium in Melbourne, Australia) so they could view the instant replays and catch all the action while still being at the stadium and experiencing that atmosphere of the live event.

The fourth generation of stadia is also focused on the multiple uses of stadiums and the flexibility to host a variety of events year round to increase revenue, and not just a particular sporting event. Functionality and flexibility is a key aspect of fourth generation stadia.

As mentioned previously, Docklands Stadium in Melbourne, Australia (also known by its current corporate sponsorship name, Etihad Stadium) is a perfect example of a fourth generation stadium. Opened in 2000, Docklands Stadium incorporates a high level of flexibility and functionality. Though its usual configuration consists of a sporting event on an oval, Docklands Stadium was the first stadium in Australia to have the capacity for moveable seating within the stadium itself. In this regard, the stadium is flexible and a multi-function facility. Each of the four tiers of seating on the first level of the stadium can be moved up to 18m forward into a rectangular configuration for sports that require a rectangular oval, such as rugby or soccer. There are issues associated with this however, notably the time required for such reconfiguration and the inherent damage to the arena surface.

The stadium has also played host to not only sporting events, but concerts by recording artists, music festivals and performances such as professional wrestling and boxing. It also features a retractable roof, the largest of its kind in the Southern Hemisphere (Etihad Stadium 2013) and opens or closes within 20 minutes. It also includes a wide array of amenities, such as capacity for approximately 53,000 spectators, 13 function rooms, 66 corporate boxes, 1000 video seats, 2,500 car park spaces below the ground, numerous restaurants and cafes, a museum and stadium tours (Etihad Stadium 2013).

Figure 4.4 depicts Docklands Stadium (currently commercially known as Etihad Stadium) and shows the arrangement of its retractable roof when open. When closed, the two halves of the roof come together to meet in the middle and provide shelter over the arena and the spectators within the stadium itself.

Testament to the rise of fourth generation of stadia is Stadium Australia in Sydney, Australia and Wembley Stadium in London, England. Stadium Australia, built for the 2000 Sydney Olympics, has one million square feet of area dedicated to bars, restaurants and general areas for spectators to go when not watching the action on the field. By contrast, Wembley Stadium (opened 8 years after Stadium Australia in 2007) had double this amount – two million square metres of area for bars, restaurants and spectators (Culf 2005). In less than 10 years the requirements and size of a stadium has doubled due to the focus on spectator facilities, comforts and realising the potential of the stadia as a 365-day venue rather than just a match-day venue. Both of these stadiums could generally be considered as fourth generation stadia as they incorporate many of these characteristics that define the fourth generation of stadiums.

Figure 4.4: Docklands Stadium in Melbourne, Australia with its retractable roof open.

The last and current generation of stadia are those that not only incorporate new stadia and all past evolutionary changes, but also start to focus on unique ideas and designs for stadia that not only make it stand out, but also incorporate it with the surrounds of the city in an attempt to aid in urban renewal of the area.

Some of the world's newest stadia being constructed are not just stadiums, but entire sporting and entertainment precincts. The stadiums themselves tend to be a draw card for tourism and nightlife, as they attract many people to the area at certain times of the week. The potential of stadia to shape new cities and regenerate decaying areas of old cities has been realised, and it is influencing stadia placement and infrastructure all around the precinct.

The focus of fifth generation stadia is about making sustainable and integrated environments where stadia become embedded within the fabric of a city. The most modern and newest stadia often act as a catalyst for diversity, vibrancy and regeneration within a city.

Emirates Stadium in London, England is a perfect example of this. Home to English football club Arsenal, Emirates Stadium was opened in 2006 as a replacement to its former Highbury stadium due to the restrictions imposed by the capacity of that stadium.

Emirates Stadium was built on a site known as Ashburton Grove. Though only 460m from the previous Highbury stadium, Ashburton Grove was at the time a waste disposal and industrial estate, mostly owned by the local council. The site was bought out by the football club and the Emirates Stadium was constructed on the site. As part of this new stadium, a redevelopment of the surrounding precinct was undertaken, with a redevelopment of the local Drayton Park, a new industrial waste estate constructed nearby and conversion of the former Highbury stadium into a residential apartment area. Commercial and office buildings were also constructed as part of the redevelopment of the area. Improvements were also given to local underground railway stations, and overall the new Stadium scheme generated 1,800 new jobs and 2,300 new homes (London Evening Standard 2001).

The stadium was constructed on a site that was mostly derelict and light industrial land that was more of a blight than a benefit to the local community.

Figure 4.5 shows the Emirates Stadium and its surrounds. As can be seen to the south of the stadium (bottom of the figure), the stadium has led to urban renewal and construction of a series of residential apartment buildings. To the east of the stadium, a commercial/business park has been constructed (as well as a museum and other infrastructure associated with the stadium precinct). The construction of this stadium on this site has led to an urban renewal of the area, and has in turn benefitted the local economy and acts as an attraction for businesses within the area.

Figure 4.5: Emirates Stadium and surrounds in North London, England (Arsenal Football Club 2013)

4.8 Conclusion

Stadia have evolved over time based on the needs of spectators. Stadiums have been forced to change or alter their strategy in order to maximise attendances at events. Without spectators, large stadia would be empty and not financially viable. If they are not financially viable, they can fall into disrepair and can become a blight on the community. Spectators are the key ingredient to stadia, and the new demands and expectations that have risen of stadia over time have forced engineers to meet these expectations, and then go further in implementing a safe, comfortable and attractive venue for all members of the community.

The five generations of modern stadia highlight this point very well, as stadia have undergone several different changes and the shift and focus has changed significantly over the last century, which is driven primarily by spectators or numbers of viewers tuning in via television on an international scale.

5. Chapter Five: Modern Stadia

5.1 Introduction

Modern day stadia are unique structures that highlight the urban landscape of a town, and are often a focal point in a city. They strive to incorporate new and different ideas to enhance the experience of the players, spectators and home television viewers. Modern day stadia enhance the local economy, boost tourism and provide an opportunity for spectators to witness their local sporting heroes in action.

Modern day stadia also have new ideologies, from sustainability to environmentally friendly and zero-emission contributors. This has led to amazing evolutionary advancements in stadia technology, design, construction and utilisation.

5.2 Stadium uses

Without a doubt the greatest driving factor behind most stadia construction is its need to host sporting events. Professional sports represent a steady patronage and use of a stadium for the majority of the year that would not necessarily be gained with the infrequent nature of other stadia uses such as one-off events or music concerts.

Though in the past stadiums were typically designed for one purpose (i.e. one type of sport such as football or basketball), modern stadiums are often built with a multi-purpose mind-set. This is however dependent on the nature of the primary use. For example, baseball stadiums in North America have a unique configuration, and thus are usually purpose built for that sport. However in other countries such as Australia, modern stadia are now being constructed with a multi-purpose function in mind, due to the variety of different sports being supported and followed in the country. A multi-purpose stadium can be designed to for an oval field for sports such as cricket and Australian Rules Football, and could also be modified to allow rearrangement of the stadium for a rectangular requirement such as football, rugby league or rugby union.

Multi-use stadiums are of a greater degree of difficulty to design and construct for than single function stadia, however they present the opportunity for greater flexibility and ultimately return greater profits.

5.3 Playing surface and pitch selection

As many stadia are designed for sports, the playing surface within the arena is largely dictated by the rules that govern that sport. However, in the case of multi-function stadia, the larger range of requirements dictates that playing surfaces may vary or have special requirements within the stadium.

Natural grass is widely used in modern stadia due to its relative inexpensiveness when compared to the alternative artificial turf. Natural or real grass is seen as having a greater 'playability' when it comes to sporting arenas, and also has less of the health and safety risks that are associated with artificial turf. Natural grass has a number of advantages as it can be tailored for different sports or for the perfect speed for most ball sports when wet or dry, depending on the length it is cut at. It is also self-repairing to an extent in that it can be regrown in areas of pitch damage with minimal interference to the rest of the pitch.

Natural grass does have a number of disadvantages however. As it is a living ecosystem, it requires sunlight, water, constant care and attention, and can be prone to issues such as disease or bug infestations that can compromise the playing surface. With the increased focus of constructing stadia with an enclosed roof, it also inhibits the ability to maintain the pitch adequately as exposure to sunlight and rain would be significantly reduced.

It also limits the ability of the stadia to host events due to concerns on the effect that multiple events over a short period of time would have on the playing surface. Natural grass also has a limited useful life on the pitch due to the intensity and frequency of the use it receives. As such, it is often required to be entirely replaced – a time consuming and expensive effort.

Artificial turf (as shown in Figure 5.1) was created as an alternative to natural grass in the hopes of eliminating some of the aforementioned problems that natural grass suffers from. Artificial turf first gained widespread attention in the 1960s when it was utilised in the newly constructed Astrodome in Houston, Texas. Artificial turf such as that in was used to replace the grass field for the Astrodome (a purpose-built Major League Baseball stadium) as the semi-transparent ceiling panels could not allow enough light into the stadium to enable the grass to grow.

Figure 5.1: Cross section of typical artificial turf used in sporting pitches (Mathisen 2007)

Whilst this artificial product has its advantages such as the lower requirements for water, sunlight and constant attention, it also has its downsides. Typically artificial turf is usually installed on concrete or some other hard surface. It offers little resistance to impact and as such has been blamed for high number of impact injuries to athletes, resulting in the compromise of the health and safety of those that utilise the arena. Different behaviour is also experienced in relation to the natural bounce of a ball off the surface. Artificial turf tends to provide a faster surface with a lower level of resistance for ball sports, and as such balls would travel faster and bounce higher which affected the nature of the sport itself. Footings for players when wet can also be different to that of grass when wet and can severely impact on the way in which a sport is played.

Presently, the majority of stadia around the world use natural grass rather than artificial turf due to the inherent risks associated with the artificial turf, as well as the aesthetically displeasing nature of it. Technological developments have enabled clubs to continue to use natural grass, and in cities and countries where sunlight is restricted in certain months of the year or the cold climate makes it hard to continually grow natural grass, technological innovations such as artificial lights to imitate sunlight and below-pitch cooling/heating systems are used to counteract some of the problems associated with natural grass surfaces.

5.4 Spectators

Spectators are an integral part of the stadium. Without spectators, the ability of a stadium to generate revenue is severely impacted, which is why spectator focus in stadium design and construction is such an important factor.

Modern day spectators demand comfortable stadiums to view events, as well as excellent views and sight lines of the action of the entire field to rival the experience and views they can obtain from the comfort of their own home and television broadcasts.

5.4.1 Stadium capacity

The spectator capacity plays a huge role in the stadium size, amenities and overall design. Designers and clients must strike the right balance between the required capacity and desired capacity. So a 75,000 seated stadium would be impractical if the average attendance at sporting events within the stadium is only around 30,000 spectators. This would increase the expense, required size, design and construction time which is simply a waste if not required and not good engineering practice.

Sporting organisation and design teams often over-estimate the required ground capacity, in part due to general optimism in increased crowd attendances. Clubs sometimes feel that a larger stadium would translate into larger crowds and attendances however this is not always the case.

John, Sheard & Vickery (2007, p. 124) discuss the golden rule for stadiums and ground capacity, and that 'a golden rule is to never increase stadium capacity beyond what is known to be necessary and can be demonstrated to be affordable both in capital cost and running cost.'

Generally, the capacity of a stadium is determined based on a number of factors:

- The primary sport or event to be regularly hosted at the stadium.
- Practical limitations of the selected site.
- Available and required capital and ongoing running costs.
- Size of the catchment area of the stadium surrounding the development.
- Aspirations and goals of the owners, sponsors, stakeholders and affiliates.

- History of the site, sporting club and sporting organisation.

Whilst these factors must be considered, there are further attributes to take into account to determine the overall stadium capacity. The quality of the view and the distance from the action is also important, as are the sightlines of the spectators, safety of spectators and employees, requirements for amenities and support facilities and event management of event days. All of these factors need to be discussed and examined both individually and as a whole as they must all function in harmony with one another.

5.4.2 Sight lines

Sight lines and viewing perspectives are critical for spectators. Spectators must be able to see over the person in front of them, but at the same time not block the view of the person behind them. Many mathematical calculations are used to design adequate seating accordingly for the sightline.

Engineers use what is referred to as the C-value in determining sightline quality and requirements within seating areas of a stadium. The C-Value is 'a variable that defines the quality of the spectator's line of vision over the head of the person in front of them, commonly known as 'the sightline" (UEFA 2011). Simply put, a higher C-value means a clearer sightline for that spectator, and resulting in a better view of the pitch. Good stadium design will incorporate high C-values for spectators for the entire stadium, however there are design challenges associated with this and it can result in an increase in the overall height and width of the stadium. Depending on factors such as budget and the size of the site, this may or may not be entirely feasible.

To calculate the C-value, the following formula is used:

$$C = \frac{D(N+R)}{D+T} - R$$

Where

C = the C-value

D = the horizontal distance from the eye to the point of focus (usually near the touchline)

R = the vertical height from the eye to the point of focus (usually near the touchline)

N = the riser height of each individual seating row

T = the tread depth (i.e. the depth of the individual seating row)

(Culley & Pascoe 2005)

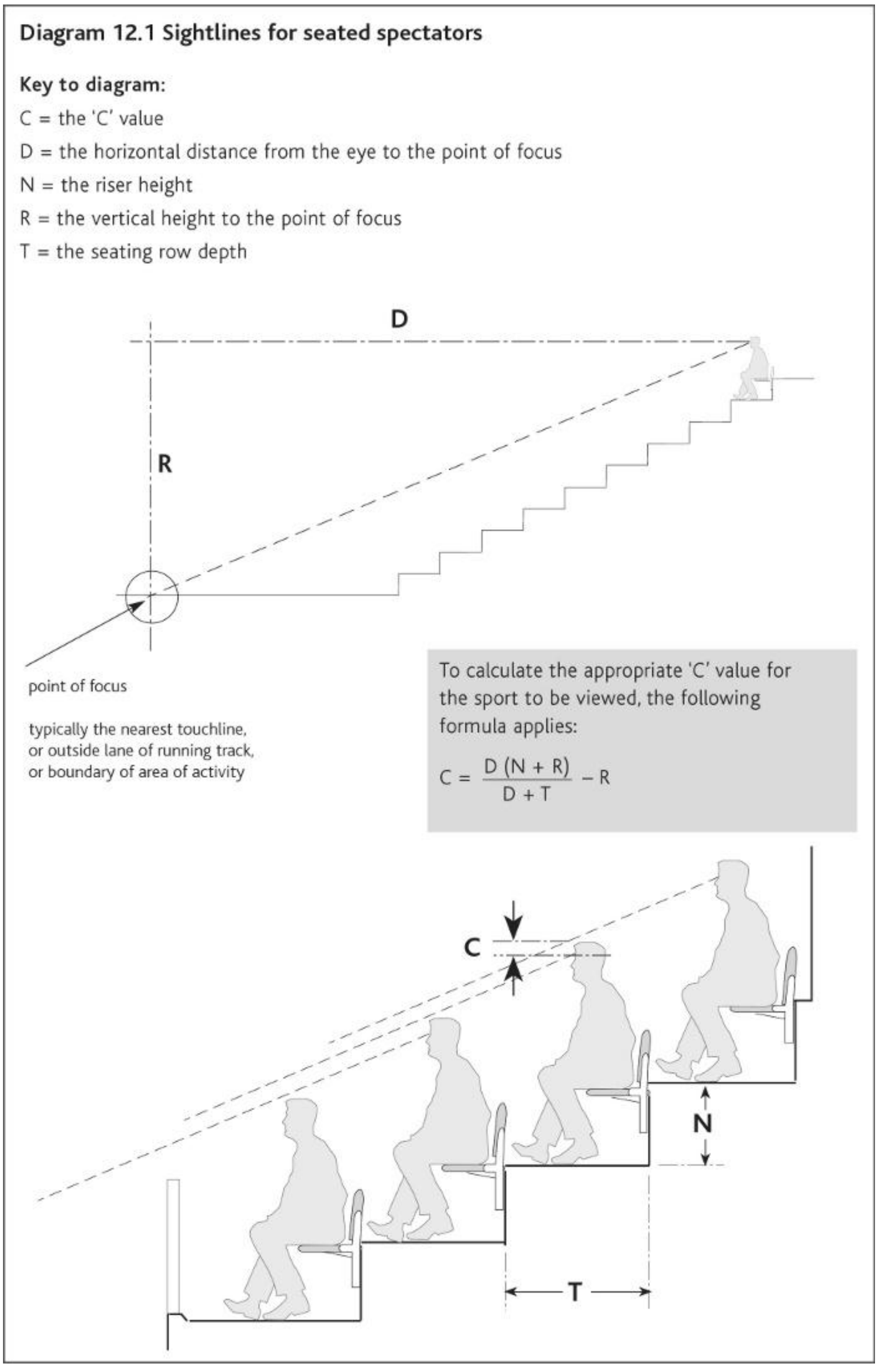

Figure 5.2: Sightline calculations for seated spectators in a stadium (Department for Culture, Media and Sport 2008)

Figure 5.2 illustrates the variables used within the C-value calculation and their real life applications. The C-value must be calculated in order to ensure that proper sightlines are possible from every seat in the stadium. At some stadia that hold events such as horse racing or where hats are a common part of the spectator attire, the C-value can be up to 150-200mm. At other sports where the action does not regularly come close to the edge of the pitch near the spectators such as cricket, a smaller C-value in the range of 90mm is sometimes acceptable. For sports such as soccer and football which utilise the entire field, a C-value of 120mm is often used. All of this in turn affects the angle of the seating as well as the dimensions, the leg room and space between rows and the tread depth as well. The most challenging part for the designers and engineers is fitting in as many spectators as possible, all the while maintaining an appropriate sightline value and comfort level.

5.4.3 Viewing distances

Viewing distances and angles of the spectators tend to dictate the arrangement of the stadium and the size. Engineers and architects much determine the maximum viewing distance appropriate and design accordingly.

Calculation of the maximum viewing distance for spectators is based on the physical limitations of the human eye. Research has shown that a human eye with perfect vision (i.e. without impairment) finds it difficult to perceive anything clearly that subtends an angle of less than 0.4 degrees, especially when the object is rapidly moving such as in sports.

The result of this is that for ball sports, the maximum viewing distance generally differs between sports due to the variety of sizing used for balls. For example, a rugby ball has a diameter of approximately 250mm. Calculations sets the ideal viewing distance at less than 150m between the spectator and the extreme corner of the field (the furthest part of the field/pitch), with the absolute maximum at about 190m. For a sport such as tennis where the ball is of considerably smaller size (average 75mm diameter tennis ball) the ideal viewing distance is 30m or less.

This calculation is not always practical however. For some sports, the ball has a such a small diameter when compared to the size of the large field (such as field hockey, ice hockey and cricket) that it would be impossible to place spectators within the theoretical maximum viewing distance as it would be so small. Therefore, a realisation that the spectators will have to watch the players rather than the ball in some cases is needed. The fact that spectators are not at ground level but at gradually increasing elevations also further complicates the requirements for viewing distances of spectators.

The nature of a sport also influences the arrangement of spectators. For most sports, there are optimal viewing areas or locations alongside the pitch, however there are also the traditional sections that highly motivated team supporters tend to congregate in.

Figure 5.3 illustrates the typical viewing distances of a football (soccer) field based on some of these calculations. Using these calculations, the optimum viewing distances can be determined, and dimensions (lengths) of spectator stands can be modelled based on this. Ideally, the majority (if not all) of the spectator seating areas will be within the assumed optimum viewing distance of 90m from the centre of the pitch. The following Figure 5.4 shows some potential seating arrangements based on the optimum viewing distance calculations in Figure 5.3. Arrangement (c) in this Figure 5.4 offers the best and ideal arrangement for spectator viewing as all spectators are located within the assumed optimum viewing distance circle radius, however often due to constraints on location or other factors this is not always possible and other arrangements such as (a), (b) or (d) are forced to be considered.

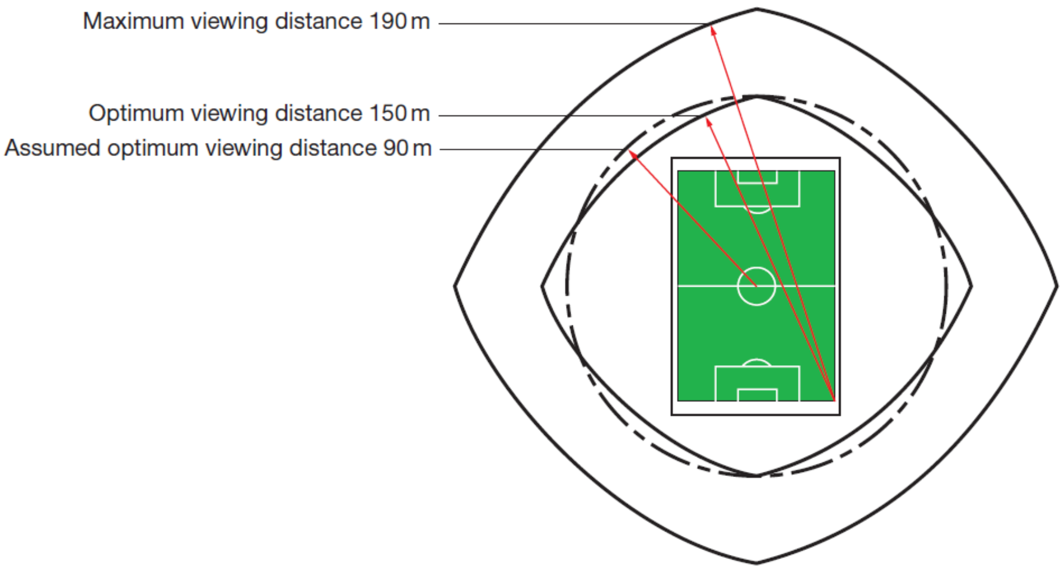

Figure 5.3: Relationship between the playing field, optimum viewing distance and maximum viewing distance of a football pitch (John, Sheard & Vickery 2007)

Figure 5.4: Potential spectator layouts based on the optimum viewing distances of the field (John, Sheard & Vickery 2007)

Appendix B details the ideal or preferred viewing areas for a number of prominent sports around the world. Note that these are the preferred viewing areas around an arena for that particular sporting event. It does not necessarily mean that stadia should not have spectators areas built on other sides of a field; however the spectator's viewing experience is likely to be worse off than if they were in the area highlighted as the preferred viewing area in Appendix B.

5.5 Players, athletes and participants

After the spectators, the second most important people to consider when designing and constructing a stadium are the athletes (or participants in the event). They are the focal point of the action within the stadium and the entire reason that the spectators patronise the stadium. Without the athletes, the need for a stadium would not exist.

The athletes and competitors dictate the requirements of the pitch, as well as heavily influence a number of safety factors (such as requirements for barricades and separation between spectators and athletes). Athletes are considered celebrities in today's society, and they are often viewed as heroes and role models, or equally villains and public enemies. They sometimes require adequate protection against over-enthusiastic fans, and the need for separate entrances and separation and barricades in public areas is apparent.

The safety of the athletes is also paramount, and thus the quality and type of pitch is extremely important. As discussed previously in Section 5.3, the rules and regulations of the primary sport can influence this, however in a stadium with the need for a multi-use surface, difficult choices must be made about design priorities that directly account for the safety of the athletes to ensure a safe working environment and reduce the risk of serious injury that may be present with particular pitch surfaces or designs.

5.6 Site selection

Site selection and location is incredibly important when constructing a modern stadium. In the past, there was a mentality of "if you build it, they will come." In other words, site location was not of a huge concern as people would travel to the outskirts of a city when needed to watch their team. The invention of television changed all this, and site selection became increasingly important given the ability of present-day stadia to regenerate areas of urban degradation.

Many new stadia tend to be built on brownfield sites in large urban areas, close to central business districts (a brownfield site being defined as land that was previously used for industrial or commercial purposes that may be subject to low levels of pollution or waste). Because of the large land requirements for the stadia itself as well as the surrounds and new transport infrastructure that would be required that are most likely not already in place, brownfield sites are becoming more and more apparent as the ideal site for a new stadium.

As is common with the use of many of these sites, there are major risks that lie with the ground and the site itself. Whilst the land can sometimes be obtained for a lower cost than it would for similar sites nearby and can more easily be obtained by the government, the risks of heavily contamination of the soil or groundwater can sometimes outweigh these benefits and end up drastically increasing costs for site works, especially if the site appraisal has not been undertaken properly.

5.6.1 Locational factors

In the present day it is technically and physically viable to construct a safe, comfortable, appealing and functionally efficient stadium at any site within a town, such as within the town centre or on the outskirts, or anywhere in-between, provided that there is sufficient land for the requirements of the stadia and that the stadia is compatible with its surrounding environment (i.e. does not lead to or provoke undesirable or anti-social behaviours). The deciding factors for the location based on this are:

- Land availability
- Land cost
- Land use rules and regulations from local, state and federal government levels
- Spectator accessibility and client base

Once all of these factors have been taken into consideration, an appropriate site location can be selected. However due to the restrictive requirements of stadium locations, it is not uncommon that stadia share sites with commercial and/or retail complexes, such as the Skydome in Toronto, Canada which shares its site with a large retail shopping mall.

5.6.2 Geotechnical factors

Though a location may be chosen for a stadium based on locational factors, geotechnical aspects will still affect the selection of a site.

Firstly, the extent of the earthwork requirements will need to be evaluated and considered. Extensive work for cabling, pipework & amenities as well as excavation and filling operations are required, depending on the nature of the site and the chosen pitch level and associated stadia design.

The approximate locations for foundations will also need to be assessed and the loads that will be transferred to them to determine if the soil can handle the stadia and earth pressures as well as the heave of the ground. Large horizontal forces may require large thrust blocks or similar, which will need to be taken into consideration for space requirements as well as the capacity of the shallow soils that would be subject to the thrust blocks.

Proper investigations into the geotechnical risks at a particular site are very important and valuable, especially in the long run. There are a number of high risks associated with the geotechnical foundations of a stadium, and any disproportionally small expenditure into the investigation for the inherent risks is often at the peril of the engineer, developer and designer.

In the United Kingdom, approximately 20% of all construction projects are delayed by over a month due to unforeseen geological or ground conditions at the site (Culley & Pascoe 2005). For the most part, the cost of these delays usually exceeds the costs of the initial investigation if it had it been done properly or at all during the preliminary phase of the project. For structures such as stadia, this can be catastrophic to the project timeline and associated deadlines, blowing out construction times and costs. For stadia on tight deadlines or under the watchful eye of the international media (such as stadia infrastructure for the FIFA World Cup or a summer or winter Olympic Games) this can even be a source of national embarrassment to those countries involved.

Some of the major hazards that may be encountered during stadia construction and should be properly investigated prior to the construction include:

- Ground conditions such as geological and geomorphological hazards.
- Groundwater levels and pressures.
- Buried obstructions and obtrusions.
- Heritage and traditional ownership, including the presence of historically or archeologically important artefacts.
- Contaminated ground and groundwater.
- Historical usage of the site (for example waste disposal sites or dumping grounds for hazardous substances).
- Seismic risks attributed to tectonic plate movements.
- Historical mining and/or excavations.
- Buried services including any large or extensive tunnel networks (such as underground transport systems).
- Vegetation or remnants of vegetation, such as intrusive weeds or root systems that could potentially impact the stadia.
- Habitats for native or endangered flora or fauna

5.6.3 Supporting infrastructure

A stadium is a destination for members of the community to congregate and experience an event together. It is a structure that will experience high volumes of people over a short period of time during events, and adequate infrastructure needs to be in place to ensure that accessibility to the stadium runs as smoothly as possible.

As there are such large numbers of spectators within a short period of time attending an event in the one location, it will undoubtedly place a great deal of stress on the traffic and transport infrastructure, such as major roads and freeways, pedestrian malls and areas, and public transport infrastructure such as trains and buses. A proper and thorough analysis of the site and its intended parking and transport factors must be considered in any site analysis for new stadia.

Well-developed links are required between the stadium and public transport, especially for the scale of stadia being constructed today. Generally around the world there is a growing trend and reliance on public transport to ferry passengers to and from a stadium for (usually) a local sporting event. The proximity of a stadium to existing railway stations, bus stations, or other transport services such as ferries is a major advantage.

Generally however a new stadium constructed at a new location will not have the required transport infrastructure within close proximity. Therefore upgrades are required to existing services, or in the case of constructing stadia on a Greenfield site (for example, on the outskirts of a city where land is plentiful and relatively inexpensive) a whole new transport infrastructure and transport link is required. These upgrades or new facilities required for stadia should be carefully considered in connection with the stadium capacity and physical location, as transport or support infrastructure issues can play a huge part in stadia location selection.

Secondary issues such as noise controls and restrictions, and illumination from stadium floodlights also need to be taken into consideration, though often there are forms of controls that can attempt to alleviate these issues and as such they may or may not be crucial parts of the stadium design. However, such issues are still required to be considered during the preliminary design phase to ensure that a stadium has minimal negative impacts to the surrounding environment.

5.7 Structural materials

The availability of materials and evolutions in technology and the way that those materials can be employed within a stadium play a large role in the way a stadium is designed. Primarily, this is related to the overall look, definition and aesthetic qualities of the stadium; however it also influences the functionality, the size and is the reason for some key or unique features in modern stadia.

5.7.1 Concrete

Concrete is a combination of water, sand, cement and aggregate mixed to a specific ratio to provide a material with a high compressive strength. Steel reo is often added in specific formwork patterns to the concrete as reinforcement to improve the tensile strength of the material.

Concrete was used extensively by the Romans to construct their structures (albeit in a different form to modern day concrete in what is referred to as Roman concrete) due to this high compressive nature of the material. Much of the Roman construction was based around the principle of the arch structure, where compression is the main force and tensile strength of the material is less regarded.

This trend continued on into modern stadia. Historically many first, second and third generation stadia were constructed using concrete as the majority building material and not much else. Concrete (mainly in the pre-cast form) was utilised to construct the seating terraces for the spectators, with pre-cast concrete used as walls around the outer edge. As these earlier stadia were focused more on spectator numbers than capacity, concrete provided a cheap and effective way to construct a stadia with little regard or requirement for additional structures such as roofs or enclosures within a stadium.

As stadia design evolved into fourth and fifth generation stadia, the majority of construction material within a stadium started to shift from concrete to steel. However this was not due to a perceived decrease in the amount of concrete used in a stadium, but rather due to the increase of the amount of steel used within a stadium. Stadia being constructed in the present day still often utilise concrete for the seating profile, however it is the exterior façade as well as the internal structure such as the covering over spectator seating areas that has progressed and in turn increased the amount of steel used within the design and construction of a stadium.

Concrete still has many benefits over steel that make it widely used in certain aspects of stadia construction. It is naturally fireproof and provides a great deal of compressive strength when designed properly. With the possible inclusion of admixtures in concrete mixes, it can increase its already high durability, workability and physical properties.

The use of concrete in stadia engineering does have its downsides though. In the use of in-situ concrete (where the concrete is poured on site into framework), costly formwork is required, and it is labour intensive for both preliminary and construction phases. Any in-situ concrete utilised is also heavily dependent on factors such as the weather for construction, which has the potential to dramatically increase a project's timeline and budget. Pre-cast concrete does counteract some of these inherent problems in that it is cast indoors in controlled conditions and not subject to adverse weather conditions, however pre-cast concrete is costly and not always an option for some stadia designs.

Concrete is also aesthetically displeasing in its natural form. It is a hard, cold material that does have the ability to be painted should the surface be smooth enough, however this requires more time, effort and money. Cladding of some sort can be added and attached to the exterior of a concrete wall; however this too is costly and can require maintenance and result in any cost benefits gained from the durability of concrete disappearing.

5.7.2 Steel

Whilst concrete paved the way for the initial structures of stadia, the increased prominence of steel over time and the addition of its use in differing ways has led to stadia that improve comfort, design and the overall experience within the stadium. Steel can potentially be the difference between creating something ordinary and creating something truly unique.

Steel is incorporated in design as an alternative to concrete. It has the highest strength-to-weight ratio of any construction material, and is incredibly flexible in terms of different ways to address design requirements. It also tends to have uniform material properties (based on the type/rating of steel chosen) whereas the properties of concrete are heavily dependent on the mix and the conditions that the concrete is cast in (for example weather during the pour or curing process can affect the ultimate strength of the concrete). One advantage that steel does possess is that both steel and concrete have virtually identical coefficients of thermal expansion. This means that changes in temperatures (external temperatures; the weather for instance) are not a major problem when the two materials are combined.

The downsides of using steel in stadia design are its limitations or disadvantages. Steel is not a natural fireproof material unlike concrete, and requires adequate treatment and maintenance to ensure its protection and continual safety. Steel sections can be encased within concrete which will provide a natural barrier, but for any exposed steel members or sections, treatments such as spray on mineral fibre or vermiculite cement can be employed. This detracts from the aesthetic appearance of the steel which can sometimes be slender and unique, and also subsequently increases costs. These factors must be considered in the design as well any project timeline or budget.

Steel can also fall victim to its surrounding environment as it can be susceptible to corrosion which leads to a reduction in the strength and can ultimately cause failure. It requires treatments such as galvanisation, weather-proof paints or technological controls such as cathodic protection. Again this can be costly, but it is a requirement to ensure the safety and the lifespan of the structure.

Given the versatility of steel within design, it is widely used in industry for construction of not just stadia but a variety of structures. It brings the ability to span long spaces in an economic and somewhat graceful manner. For projects such as stadia, the ability to fabricate the steel off-site at the same time as on-site concrete works achieves efficiency in both time and cost management.

5.7.3 Other materials

Materials such as glass, bricks, coated steel panel cladding and ETFE (Ethylene Tetrafluoroethylene) panels usually contribute more to the aesthetics or cladding of a stadium rather than as part of the structural support system itself.

These materials are usually selected by the architect for the stadium, and are often chosen based on availability near the site of the stadium (i.e. lower costs in some countries for particular materials lead architects or engineers to select these materials). Some materials for the façade may also be chosen to represent the region that the stadium is to be built in, and the project team want the stadium to be integrated as part of the local community.

Some materials such as the ETFE panels are chosen more so for a unique design and to create something truly spectacular, such as the Allianz Arena in Munich, Germany or the National Aquatics Centre in Beijing, China.

In this present day, materials are also selected based on environmental and sustainability factors. Materials that present advantages to the environment or represent sustainable efforts such as ETFE panels that absorb solar radiation and reduce thermal loss are highly regarded as viable construction materials in modern stadia.

5.8 Structural support systems for stadium roofs

More frequently modern stadia are incorporating a roofing system for stadia for a number of reasons. It can improve spectator comfort, and improve spectator volumes in colder climates. It can also be necessary for certain sports to ensure play continues year round (for example in sports such as tennis a roof can ensure continuous play during rain or at night without compromising the surface of the pitch or cancelling the event, such as at Centre Court at Wimbledon in London).

A plethora of differing roof structures are employed by modern stadia all over the world, and the variety represents the different needs of individual stadia around the world. The trend of modern stadia in the United States of America and Japan especially has been towards fully covered stadia, though fully covered stadia will lead to a dramatic impact on the surface quality of the pitch (depending on the type of pitch being employed at the stadium).

5.8.1 Design considerations

A majority of stadia hold events in the afternoons or evenings. For events held during the afternoon, shading of spectators from the sun must be a consideration in both the type of roof selection as well as the design. As the sun will be subject to differing heights for an afternoon match throughout the year (due to the continual rotation of the earth and the transition between summer solstice and winter solstice), this must also be taken into consideration. In addition, the shadow cast upon the pitch by the roof and stand will also make a difference and may impact on the performance of the event on the pitch, so this must also be taken into careful consideration.

Shelter of spectators from wind and rain is also a major consideration. It has been noted that continuous roofs arranged in a circle or ellipse, as opposed to separate roofs or gaps between them, usually have a calming effect on the air and wind within the stadium (John, Sheard and Vickery 2007). However the reduced airflow in the stadium it can also result in inadequate drying of a pitch (especially grass) after a rainfall event which may inhibit activities or events at the stadium.

The roof and associated support system materials should also be designed that it does not impact on the views of the spectators, and should be high enough that the majority of the spectators in the stadium are able to keep sight of the ball (if applicable) when it rises in the air.

Design loads are also an important factor for the roof material and overall design, as well as the choice of roof style. Much of the roof is directly or indirectly exposed to the elements (rain, wind, snow, sun) and as such will only have a certain life cycle or design life. The material selection should be based on this (as well as the cost and impact to the overall budget) in order to get the most cost-effective and durable structure available. Elements that have shorter life cycles within the structure such as claddings should be designed for easy access and replacement for the inevitable time that they require replacement.

Design against loads such as snowfall on the roof as well as wind uplift are also design issues to be taken into serious consideration and failure due to this can have a dramatic impact on the safety of the spectators underneath it, not to mention the damage and costs to the stadium itself.

5.8.2 Post and beam structure

Perhaps the most simple of the roof support system designs, a post and beam roof consists of rows of columns parallel to the pitch inside the stadium that support a series of beams (or trusses) that in turn support the cladding of the roof itself. This system is relatively cheap and simple and was used extensively in early stadia for roofs. However the major disadvantage of such a structure is that the spectators views are obstructed by the periodic columns at the front of the roof, and such roofing structures are hardly used at all in current modern stadia. Figure 5.5 shows a diagram of a typical post and beam style roofing structure.

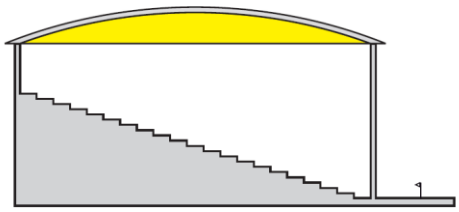

Figure 5.5: A post and beam style roofing structure (John, Sheard and Vickery 2007)

A variation on the post and beam structure is the goal post structure. Similar to the post and beam structure, the roof is simply supported by columns and beams (or trusses); however the columns are only at the two ends of the stand with none in-between and the entire roof length if supported by the span of a single beam. This however also has its limitations, as corner seating within a stadium would still be impacted by posts and it cannot be designed with a curve or to go around corners without compromising aesthetics or spectator views.

5.8.3 Cantilever structure

A cantilever roofing structure is held down by weights or securely fastened at one end (the outer edge of the stadium) while the other end hangs free and unsupported, as illustrated by Figure 5.6.

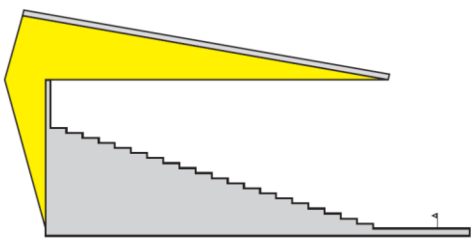

Figure 5.6: A cantilever style roofing structure (John, Sheard and Vickery 2007)

Such a structure has the advantage of being able to provide a completely unobstructed view for the spectators in the stands, and for any length of stand imaginable as well as quite a deep spectator stand as well. The can be iconic and eye-catching, with designers using them to exploit curves and long spans without front supporting mechanisms.

The issue with such a structure is related to the design and ultimately cost. Cantilever structures must be designed against wind uplift forces as well as snow and rain forces on the top, and can result in extensive and expensive reinforcement at the cantilever edge. Deeper cantilever roofing structures also require a higher level of support structure which can in turn heavily increase the cost of such a roof. If these issues can be accounted for and fit within the budget then it presents a good roofing structure design for a stadium.

5.8.4 Cable supported structure

Cable supported roofing structures usually utilise an arch (or arches) that support cables hanging down which in turn supports a roof structure. Wembley Stadium in London, England is a prime example of this (see Figure 5.14), as it utilises an overbearing steel arch to support much of the weight of the partially retractable roof at the stadium.

Cable supported structures take the weight of the roof at the front (towards the pitch) and they carry the roof through the arch or support via tensile stresses, as shown in Figure 5.7. In this figure, the yellow arrow at the front represents the cables that would be hanging from the support (typically an arch) in order to take the forces of the roof.

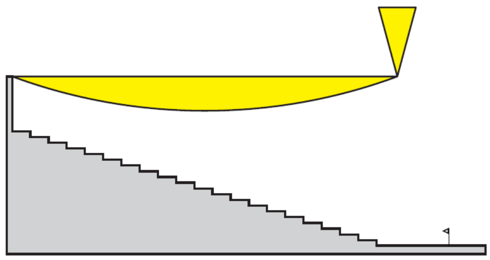

Figure 5.7: A stadium roof supported at the front by a tensile force (John, Sheard and Vickery 2007)

This type of roof structural support system is economical in material; however it may not be so for the costs. It must also be designed to be carefully stabilised and restrained against any movement or deformation which could cause parts of the structural support system to go into compression, which would likely cause the roof to fail. This type of roof can also be architecturally and aesthetically pleasing, depending on the designs of the stadium and the support system.

5.8.5 Membrane structures

Unlike the previously mentioned roof support structures, a membrane roof can be used to form both the stadium structure and enclosure. The Beijing National Aquatics Centre (see Figure 5.8) and the Allianz Arena (see figure Figure 5.11) are great examples of the use of a membrane structure for both the roof and the exterior enclosure of the stadium.

Membrane structures are typically a series of steel beams, constructed in such a way that the membrane material can be used to cover the area between the steel beams, providing a barrier and cover to the stadium. Previously, PVC-coated polyester fabric was the material of choice for membrane structures; however with the further development of technology, more designers are turning to PTFE-coated glass fibre fabric or ETFE panels.

The advantage of using such a material in the design and construction of a stadium is that generally it is translucent, and with some strategically places LEDs it means that the entire stadium can be lit up at night or changed to a different colour at the touch of a button. They also allow natural light to enter the stadium, reducing lighting requirements and costs, and allowing a natural grass surface to receive the maximum amount of sunlight possible.

There are downsides to utilising this material however. It requires a sophisticated design and a series of steel networks to achieve the desired outcome. They also require very careful detailing of rain water guttering and maintenance which can be time consuming.

5.8.6 Retractable and moveable structures

An increasing number of stadia are being designed with retractable roofs that can open and close when required. A closed roof can offer protection from sun, wind, rain and snow for the spectators and the stadium itself, while an open roof can allow sunlight and rain on non-event days to ensure natural elements are contributing to pitch growth and maintenance. Docklands Stadium in Melbourne, Australia is an example of a stadium that utilises a fully retractable roof (see Figure 4.4).

Retractable roofs have many moving parts and as a result the initial capital as well as ongoing maintenance and operating costs are quite high for this type of roof structure. Depending on the needs and requirements of the stadium itself, it is not always the best option for a stadium, especially in milder climates with less extreme variances, or in countries that are less well-off economically.

5.9 Innovative Modern Stadia

Today, designers and engineers involved with stadium design and construction are looking more and more towards new technologies in order to improve stadium functionality, design, overall look, environmental footprint and long term sustainability. This has led to incorporation of many new and unique elements in modern stadia as engineers look to create the most memorable, sustainable and environmentally sensitive stadiums.

5.9.1 National Aquatics Stadium - Beijing, China

The National Aquatic Centre (colloquially known as the 'Water Cube') was designed and constructed for the 2008 Summer Olympic Games in Beijing, China. The stadium itself was the design of an Australian architectural firm, PTW architects, and was selected as the winner in a competition process to design the new stadia of the Olympic Games in Beijing.

The structure incorporates materials that enable the stadium to function as a natural greenhouse with diffuse natural light. The majority of the structural support system is constructed from steel in what the architects termed as a 'soap bubble' pattern, with ETFE cladding panels between the steel and providing a barrier for the steel structure from both the outside atmosphere and the interior corrosive atmosphere generated from the swimming pool and associated chemicals such as chlorine.

Technological innovations have led stadia to focus on more sustainable designs and incorporate renewable resources and energy whenever they can. The ETFE material used for the National Aquatics Stadium is a classic example of this.

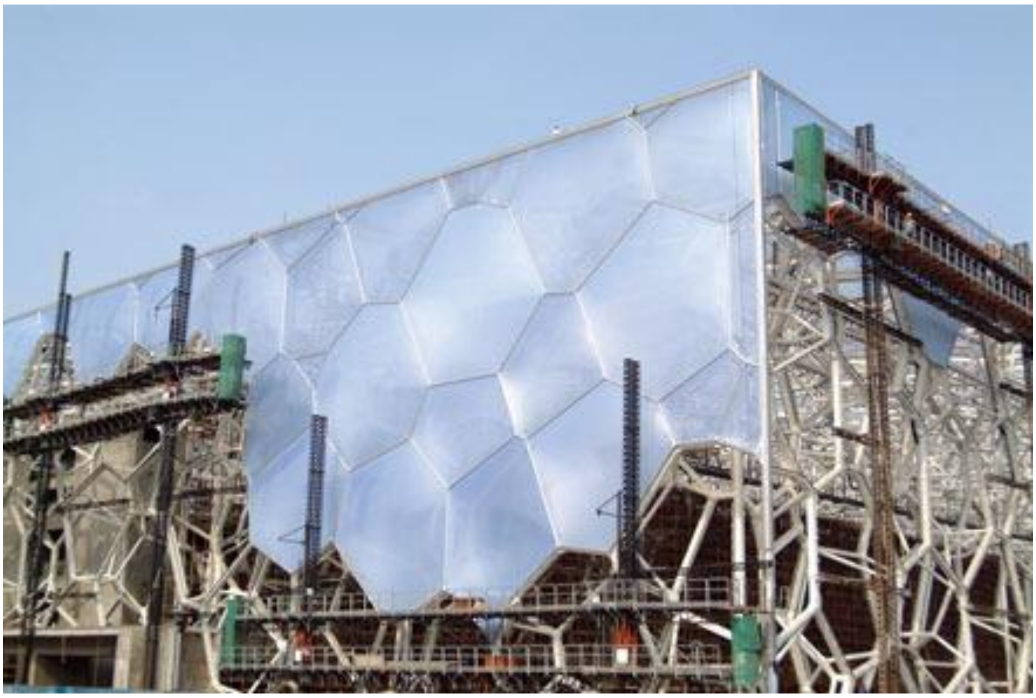

Figure 5.8: The Beijing National Aquatic stadium during construction and implementation of the ETFE cladding (China Daily 2008)

ETFE is a fluorocarbon-based polymer; basically a plastic with enormous tensile strength. When constructed into the soap bubble arrangement that makes the stadium so unique, it produces a number of ideal properties that promote sustainability and environmentally friendly structures. ETFE is lightweight, temperature resistant, insulated and recyclable material. It can also produce various levels of translucence, so with the aid of strategically placed LED lighting such as in the Water Cube, it can light up the entire exterior of the stadium, and has the potential to change colour or produce a number of different colours on the exterior façade to produce a stunning visual effect as seen in Figure 5.9.

Figure 5.9: Beijing National Aquatics Stadium at night showcasing its ability to produce many luminous colours in the ETFE bubbles (Archinect 2008)

In order to maximise the energy efficiency of the stadium, which is a big focus of modern day stadia, the ETFE panels act as a greenhouse allowing high levels of natural light to be emitted into the stadium, and as a result passively heating the enclosed swimming pools as well as the building. This has resulted in an estimated 30% reduction in the energy consumption demand for the stadium (Carfrae 2006).

The nature of the ETFE material also means that it is self-cleaning. ETFE has a very small friction coefficient, and therefore dust does not easily attach to its surface. The material will clean itself during a rain event which will wash off any dust or debris, making it a very efficient and environmentally friendly material.

5.9.2 Allianz Arena - Munich, Germany

Allianz Arena in the north of Munich, Germany was opened in May of 2005 after a two and a half year construction period. It was designed by architects Pierre de Meuron and Jacques Herzog, who also collaborated on the design on the Beijing National Stadium (the Bird's Nest). The stadium is seen as one of the most innovative stadiums in existence around the world today. Allianz Arena is home to two professional football teams, FC Bayern Munich and TSV 1860 München, and currently has capacity in excess of 71,000 spectators.

Like the National Aquatics Centre in Beijing, the exterior of the Allianz Arena is constructed from ETFE panels. 2,874 rhomboidal inflated ETFE foil panels form the panel over an area of 66,500 m^2 over the entire roof and façade, making this the largest ETFE membrane shell on any structure in the world. Like the National Aquatics Stadium in Beijing, the Allianz Arena has the ability to alter the colour of individual ETFE panels of the stadium due to strategically placed LEDs within the panels, as shown in Figure 5.10.

Figure 5.10: Allianz Arena in Munich, Germany with a number of its panels lit up with colour-changing LED lighting (Allianz Insurance 2013)

A feature of the ETFE panels at the Allianz Arena is the colour of the panels. Each panel appears white from far away (as can be seen in Figure 5.11), however when examined from close up it is possible to see that the panels are actually covered in little white dots. With this, it gives the impression of a white stadium from a distance however it actually has a transparency of 95%, and this provides the essential natural light that the grass pitch requires to grow. It also reduces the artificial lighting requirements within the stadium's catering and service areas and in turn has created a more environmentally friendly and conscious stadium.

Figure 5.11: Aerial view of Allianz Arena (Allianz 2013)

Like many new stadia around Europe and in particular countries with colder climates in winter, Allianz Arena has 27,000 metres of under-pitch heating pipelines in use (Allianz Arena München Stadion GmbH 2013). The stadium also employs cutting edge technology against such cold climates in the event of a snow fall at the stadium. The stadium's roof is equipped with 12 sensors that measure the weight of any snow on the top of the roof. This will trigger a pressure increase in the ETFE panel cushions in order to balance out any load from snow fall. In total, the roof of the stadium has the ability to resist the load of a snowfall height of about 1.6m (Allianz Insurance 2013)

5.9.3 Barclays Center - New York, United States of America

The Barclays Center, located in Brooklyn in New York, is home to the NBA's Brooklyn Nets and is the very definition of a 5th generation modern stadium. It is a multi-purpose indoor arena, and forms part of the USD$4.9 billion precinct known as the Atlantic Yards that is home to the arena as well as a business and residential complex.

After many delays including lawsuits and the global recession of 2009, construction eventually began in March of 2010, with construction of the stadium being completed in September of 2012. The capacity of the stadium varies depending on the configuration and use; for example basketball games the stadium has a capacity of 18,000 whilst for concert the stadium can hold around 19,000 people. Ice hockey games for the NHL can hold around 15,000 spectators.

Figure 5.12: The Barclays Center in Brooklyn, New York. View of the main plaza with the 'Oculus' and the subway station in the foreground (AECOM 2013)

What makes the Barclays Center so unique is its use of new technologies. Described as 'the most high tech stadium in sports', the stadium incorporates many new technologies in order to ensure the stadium is as efficient and sustainable as possible.

The stadium provides free Wi-Fi within its walls in a move designed to support a capacity crowd full of smartphones. The issues that plague most current day stadiums in relation to reception and flooding of the LTE and 3G phone networks rendering them unusable during events have been identified and solved.

There is also a smartphone application that fans can download on their phones which will allow fans to order and pay for food from their seats within the stadium, without the need to stand in lengthy queues. There is also extensive LED signage for advertisers and event related updates so fans don't miss any of the action, including a three-storey tall high definition 1080p scoreboard hung in the centre. A signature of the stadium is what has been terms as the 'Oculus', a 36m by 17m LED marquee display screen that loops 360° around a section of the plaza outside the main entrance. Figure 5.13 shows the 'Oculus' in the plaza of the Barclays Center in the front of the stadium.

Figure 5.13: The 'Oculus' in the main plaza of the Barclays Center (Abruzzese 2013)

The transit issues facing a major stadium in such a densely populated area as Brooklyn have been rectified as well. As part of the stadium construction, a new USD$76 million subway station has been constructed. This new transportation hub connects subway travellers to nine different lines of the New York subway system, and eases the flow of spectators both in and out of the stadium. In addition to the nine subway lines, the Long Island Rail Road has a stop at the arena, as well as 11 bus lines the incorporate the Barclays Center in their routes (Sheftell 2012).

On 22 July 2013, the Barclays Center was awarded LEED® Silver Certification for New Construction by the U.S. Green Building Congress, and in doing so became the first stadium in New York to achieve this status. The Barclays Centre was awarded this certification for its sustainable design and construction methods, and was recognised in five environmental categories, including water efficiency, sustainable sites, energy & atmosphere and materials & resources.

A huge focus was placed on sustainability for the stadium from the beginning, from the materials used in construction, to the construction methods and the site selection itself. Features such low-flow fixtures in the bathrooms and amenities that save millions of litres of water each year and the steel framework shading the sides of the stadium helped the stadium achieve this prestigious status. In addition, 91% of all the wood used in the building (including the basketball court itself) is certified sustainable (Ivanona 2013).

The focus on both sustainability and technology incorporated within the stadium has earned the Barclays Center a reputation as one of the most cutting edge and modern stadiums, in terms of technology and sustainability.

5.9.4 Wembley Stadium - London, England

Wembley Stadium is located in London, England and was opened in 2007 to much public fanfare. Built on the site of the original (and since demolished) Wembley Stadium, the arena has a capacity of 90,000 spectators and is a multi-function stadium, hosting football (soccer) matches primarily, however it has also acted as a host to American football (NFL) matches, rugby league and rugby union matches as well as numerous music concerts, and in 2012 it hosted events as part of the 2012 London Summer Olympic Games.

Figure 5.14: Wembley National Stadium in London, England (Wembley National Stadium Ltd. 2013)

The iconic feature of Wembley Stadium is its overbearing arch (see Figure 5.14), which supports a partially retractable roof. The steel arch at Wembley Stadium is the longest single-span roof structure in the world today and uniquely it requires its own beacons for low-flying aircraft; a rarity in stadia around the world.

In the tradition of modern or 5th generation stadia, Wembley Stadium has an enormous focus on sustainability, with a focus on six priority areas to meet their environmental sustainability objectives:

- Energy
- Water
- Sustainable procurement
- Transport
- Waste
- Marketing and communications

The stadium is powered by 100% renewable energy, and since its opening in 2007 it has reduced electricity usage and related carbon emissions by 32% (Wembley National Stadium Ltd. 2013). All non-essential lighting is turned off on non-event days, and much of the lighting has been replaced with conservative LED lighting or employed the use of low-wattage emergency staircase lighting.

Wembley Stadium is also a 'zero waste to landfill' venue, with event-day recycling rates reaching 74% (Wembley National Stadium 2013). The majority of the waste is diverted out of general waste streams into mixed recycling and food waste, with the mixed recycling being removed from the stadium to be sorted and recycled, while the food and liquid waste is taken to an anaerobic digestion plant to be broken down in order to produce energy and fertilisers (as by-products of the anaerobic waste treatment process). The remaining general waste is transferred to a 'waste to energy' facility where it is used to generate energy and fed back into the electricity grid of London.

The stadium also utilised water-saving fixtures in all of its 2,618 toilets and much of the majority of other water usage (such as for the care and maintenance of the pitch itself), and there are public awareness campaigns to try and promote the use of the public transport links to the stadium to reduce carbon emissions from cars, trucks and motorcycles.

The focus on sustainability at Wembley Stadium is one of the reasons the stadium is considered a great example of designs for new stadia around the world, and it is this focus that is promoting the research and development of further sustainability actions for stadia design, construction and operation.

5.10 Conclusion

There are a multitude of factors to take into consideration when planning a stadium, in both the design and construction fields. Stadia have come a long way from the initial stadia constructed by the Ancient Greek and Roman societies, and no longer are they simply just about attracting as many spectators as they can through the gates.

These many factors all work in conjunction with each other and are usually interrelated. In order to design the best stadia possible, one must consider these factors both separately and as one entity working together to get the best possible result for both stadium patrons and stadium owners alike.

Modern day stadia are sophisticated structures that incorporate unique ideas and architecture with the latest and most advanced engineering techniques in order to construct the most sustainable and environmentally conscious stadiums possible. The rise and prominence of new construction materials such as Ethylene Tetrafluoroethylene has enabled the vision of architects and engineers to become a reality and create something that is truly spectacular.

6. Chapter Six: Case Study of the new stadium for Perth, Western Australia

6.1 Introduction

Perth is the capital of Western Australia, and home to 1.9 million people (as of June 2012) with a growth rate of 3.6%, the fastest growth of all the capital cities in Australia (Australian Bureau of Statistics 2013). Currently, the largest capacity stadium is Subiaco Oval (currently known under naming rights as Patersons Stadium). It is a stadium with a pitch in an oval configuration for Australian Rules football (see Figure 6.1), the most popular sport in Western Australia. It also occasionally hosts other events, such as rugby union and soccer matches and music concerts.

Figure 6.1: Subiaco Oval in its existing form in Perth, Western Australia (Quartermaine 2011)

The stadium is owned by the Western Australian Government, and operated by the West Australian Football Commission (WAFC), who also owns the two major tenants of the stadium: West Coast Eagles Football Club and the Fremantle Dockers Football Club (Australian Football League teams).

6.2 Inherent need for a stadium

Subiaco Oval is the home ground of two AFL teams, the West Coast Eagles and the Fremantle Dockers. The current capacity of the stadium is 43,500 and is an all-seater stadium after major renovation works were completed in 1999.

The stadium's largest tenant, the West Coast Eagles Football Club, has a membership base of over 55,000. With the stadium's capacity of 43,500, the vast majority (39,000) of these seats are allocated to seated club members (Krol 2010). With only around 3,000 tickets available to the general public, these tickets are usually snapped up within hours of going on sale, and it results in almost all games being sell-outs and making it incredibly hard for the increasingly growing population of Perth to attend a match if they want to without a membership ticket.

There is also around 9,000-10,000 club members on the waiting list for a seated membership (West Coast Eagles Football Club 2013) at the stadium who are unable to obtain regular seats at a match. The high demand is also pushing up costs of tickets and club memberships.

As a result of the high demand for seats and tickets at a sporting event at Subiaco Oval and the inherent inability to supply the demand, the current stadium has reached its capacity (and has done for some years now), and the need for a new stadium in the city has become glaringly obvious to the entire population of Perth.

6.3 Proposal for rebuilding or new construction

Following much public pressure and media coverage of the inadequacies of the existing major stadium in Perth, the West Australian Football Commission began investigations into increasing the capacity of Subiaco Oval. In 2005, the WAFC released a plan detailing a $235 million upgrade to increase the existing stadium to a 60,000 seater venue, with construction to be undertaken in stages. The plan, which failed to highlight required upgrades to the transport infrastructure or land acquisitions, became the subject of debate amongst the general public of Western Australia.

In early 2008, the Government of Western Australia announced that Perth would be the subject of a new $1.1 billion stadium to be built on Kitchener Park (a park adjacent to the existing Subiaco Oval) to be completed in 2016 (Clarke 2008). However following a state election in 2009 which resulted in a change of government, the new State Premier Colin Barnett announced that the plans for the new stadium at Kitchener Park would be scrapped due to the state's deteriorating finances and the global financial crisis taking hold and having an effect on the state's economy.

In July of 2011 Premier Colin Barnett announced that Perth's new multi-purpose stadium would be built on the Burswood Peninsula (Government of Western Australia 2011). Currently the site of the Burswood Public Golf Course, the Burswood Peninsula is located 2.5km to the east of the Perth CBD and is already home to the State Tennis Centre as well as the Crown Casino and Entertainment Complex. The proposal was to build a sporting precinct on the site of the golf course, to link up the stadium with the State Tennis Centre and create a whole stadium precinct area to revamp the peninsula. The stadium is expected to have a capacity of between 60,000 and 70,000 and would be completed in 2018 (Government of Western Australia 2011).

6.4 Site selection

The selection of a site for a new stadium in Perth is a point of much contention within the local media and the general public. The three main options being discussed in initial and preliminary discussions were to renovate and revamp the existing Subiaco Oval, construct a new stadium adjacent to the existing stadium on Kitchener Park and demolish the existing stadium, or construct a new stadium at a different location, such as the Burswood Peninsula or the site of the existing Belmont race track (adjacent to the Burswood Peninsula site but on the opposite side of the freeway – see Figure 6.2).

A Major Stadia taskforce was set up to analyse the options, and in 2006 the taskforce undertook a review of 18 locations around the Perth metropolitan area to test their suitability for a major stadium. The review found:

- The WACA (Western Australian Cricket Ground) was suitable as a minor cricket venue only, with major cricket events (such as international events) should be held in the new multi-purpose stadium.

- Perth Oval (known at the time under its commercial name Members Equity Stadium) in East Perth was suitable for expansion for its purpose of satisfying events that required a field of a rectangular shape (such as rugby union and soccer).
- A site in East Perth next to an old power station and Subiaco (either existing stadium redevelopment or new stadium on Kitchener Park) were shortlisted for further investigation into viability for a site of a new stadium, along with the Burswood Peninsula site.

Table 6.1 shows a summary of some of the aspects investigated in the review. The report evaluated the potential options and discussed the advantages and disadvantages of each site, though it stopped short of providing a recommendation for the location of the new site.

Kitchener Park was initially selected by the Labour-led Western Australian government as it was shown to be one of the cheaper options for total development costs, while still remaining at its existing home in Subiaco, which was the desired outcome of the government and a number of its figureheads at the time, as well as the fact that much of the associated infrastructure such as public transport was already established in the area due to the current stadium. The proposal was also subject to a strong push from the local council, the City of Subiaco, who did not want to lose the economic benefits that the existing stadium provides to the many businesses, bars and restaurants within very close proximity to Subiaco Oval.

The Western Australian Government at the time agreed with the assessment, and selected Kitchener Park as the preferred site of a new stadium for the city of Perth.

Following the 2009 state election in which the then Alan Carpenter led Labour State Government were ousted in favour of a new Liberal-National State Government, the decision and progress on any new stadium was put on hold for the time being, as Premier Colin Barnett cited dwindling state funds and the global financial recession.

Table 6.1: Comparison of Shortlisted Sites for Multi-use Major Stadium (Department of Sport and Recreation 2007)

Comparison of Shortlisted Sites for Multi-use Major Stadium

	East Perth	Kitchener Park	Burswood	WAFC Subiaco Oval
Capacity	60,000	60,000	60,000	[1]55,000
Assumed Construction Completion	Sep 2011	Sep 2012	Mar 2013	Sep 2012
Total Construction Costs at Completion (excluding reconfigurable seats)	$796m	$824m	$1,122m	[2,3]$641m
Ability to Cater for all Sports (AFL, Cricket, Rugby)	✓✓✓	✓✓✓	✓✓✓	✗
Cost of Rectangular Sport Solution	$25m	$25m	$25m	[4]$318m - [5]$456m
Total Development Cost at Completion	$821m	$849m	[6]$1,147m	$959 - $1,097m
Iconic Status / Landmark	✓✓✓	✓✓	✓✓✓	✗
Urban Regeneration Capability	✓✓✓	✓	✓✓	✓
Transport / Connectivity	✓✓	✓✓	✗	✓
Major Event Capability	✓✓	✓✓	✓✓✓	✓
Ability to Expand Capacity to 70,000 seats	✓✓	✓✓	✓✓	✗
Development Timeframe (years)[7]	4	5	5.5	5
✓✓✓ = Excellent, ✓✓ = Good, ✓ = Moderate, ✗ = Low				

1. The WAFC Masterplan only provides 55,000 seats not the Taskforce recommendation of 60,000 seats. The construction cost to increase the capacity to 60,000 seats could be in excess of $35m excluding land resumptions, transport infrastructure, escalation and rebuilding the WCE facilities.
2. The WAFC Masterplan does not provide improved facilities to meet the requirements of the Western Force, in particular it does not address the issue of proximity of seats to the side line and as such would necessitate the development of a dedicated 35,000 seat rectangular stadium.
3. This includes $55m identified as the cost to acquire the properties to the south of Roberts Road to allow for the realignment of the road and the adoption of good planning principles as identified in Chapter 7.4 WAFC Subiaco Oval Masterplan.
4. The $318m cost for the 35,000 seat rectangular stadium is based on the proposals submitted by Town of Vincent ($250m) adjusted to include escalation costs as advised by WT Partnership but excluding transport infrastructure costs. This proposal however does not meet the facility requirements as agreed with the sport codes at the briefing workshops held in October/November 2006 in relation to location of corporate suites and premium seating.
5. The $456m cost for the 35,000 rectangular stadium is based on the stadium concept developed by HOK Sport Architecture ($308m) adjusted to include transport infrastructure and escalation which was developed in response to the facility requirements as agreed with the sport codes at the briefing workshops held in October/November 2006.
6. The realisation of the Burswood Peninsula attributes is dependent upon Government commitment to a much broader vision beyond the development of the 60,000 seat stadium.
7. This assumes a start of planning and design work in September 2007.

Source: Perth Stadium Consulting Team

In 2011 a new site was chosen for the stadium on the Burswood Peninsula. It was preferred by the new State Government as it was unconstrained by surrounding development and Government-owned, unlike the previously identified Kitchener Park option proposed by the previous Government. It is also a key component of the representation of the long term commitment to a broader precinct development in the Burswood peninsula and will form a permanent centrepiece of that redevelopment.

Figure 6.2 portrays on overview locational map of the new Perth Stadium on the Burswood Peninsula. It is located on the banks of the Swan River and will provide picturesque views of the city's main arterial waterway as well as the city of Perth itself.

Figure 6.2: Overview of the location of the new Perth Stadium on the Burswood Peninsula (Department of Sport and Recreation 2012a)

6.5 Stadium and precinct features

In June 2011, the State Government released a media statement detailing the announcement of the location of the new stadium in the Burswood peninsula (Government of Western Australia 2011). Key aspects of this announcement were:

- The capacity of the new stadium would be 60,000 initially, with provision for future expansion of the stadium to 70,000 spectators.
- Public transport access and upgrades would be a key feature of the new stadium.
- The stadium would be subject to 'state of the art' configuration and seating, comparable to stadiums such as Docklands Stadium in Melbourne, Victoria.
- The stadium would be afforded the latest technology in its design and functionality in order to provide a world class experience to spectators.
- A footbridge would be constructed across the river from East Perth to the Burswood Peninsula to provide pedestrian access from the Perth CBD.
- Construction will begin in 2014, and to be completed by the beginning of the 2018 AFL season (which begins in March-April).

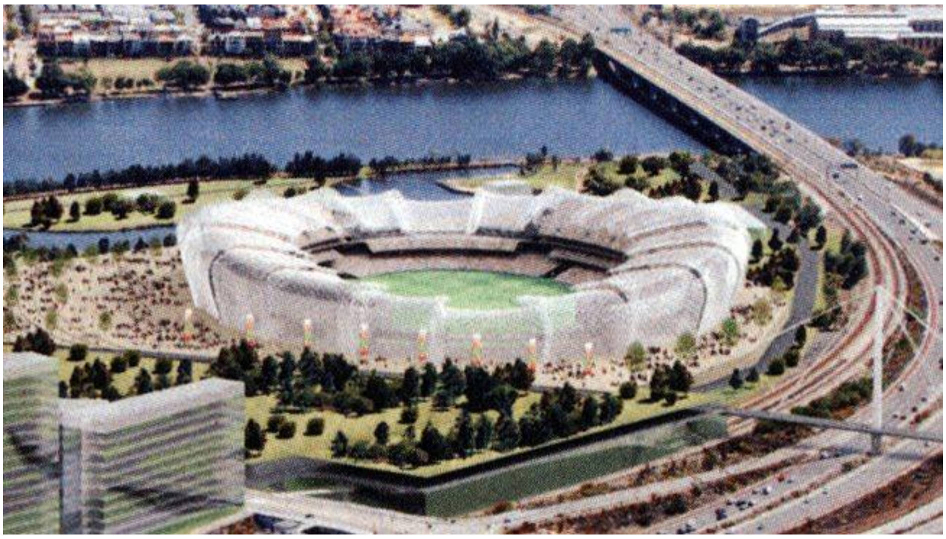

Figure 6.3: Artist's impression of the new Perth Stadium on the Burswood Peninsula (Elborough 2012)

The Government of Western Australia subsequently released a Project Definition Plan in September of 2012, outlining key aspects of the stadium and surrounding development, as well as the master plan for the stadium precinct.

This master plan further identified the vision for the new stadium. This included:

- Team branding of the stadium through lighting and technology
- Highest standard of general admission seating in any Australian stadia
- At least 85% of fixed spectator seats under a fixed roof
- Widest range of premium facilities at any Australian stadia
- Highest ratio of general admission female toilets in any Australian stadia
- Highest standard of team facilities in any Australian stadia
- Largest coaches boxes in any Australian stadia
- Fans to have 360° circulation and views of the pitch from the lower concourse of the stadium
- Spectator sightlines equal to or better than the MCG and Docklands Stadium in Melbourne, Victoria
  (Department of Sport and Recreation 2012a)

The stadium is also set to take full advantage of technological advancements and evolution in stadia design. In a design brief prepared by the Government to consortiums vying for the construction contract, the required specifications included:

- Two electronic screens at least 20m by 12m in size.
- Wi-Fi access, mobile phone quiet zones and at least 10 mobile phone recharging stations.
- Television screens spread across throughout the concourse, and radio commentary to be broadcast within toilet facilities.
  (WA Today 2013)

6.6 Site issues and geotechnical impact

Whilst the stadium is now a reality rather than merely a concept or a pipe-dream, there are a number of inherent issues with the stadium and its locational choice.

The Burswood Peninsula extends over an area of approximately 280 hectares 2.5km from the heart of the Perth CBD. The site is currently the home of the Burswood Public Golf Course, however in previous years this was not always the case. The Swan Portland

Cement Company Ltd. operated at the site from 1927, as did James Hardie Industries from the mid-1920s, up until 1981. Due to these previous and historical site activities, the site is contaminated with asbestos waste from the James Hardie operations, and cement kiln dust, bricks and contaminated soil and hydrocarbons from the Swan Portland Cement operations.

In a report published by the Environmental Protection Authority in 1998, the EPA estimates 750,000 m^3 of cement kiln dust at the site, as well as three specific zones of asbestos contamination totalling nearly 400,000 m^3 of hazardous asbestos waste within the area. The report mentions that in its present state (in 1998) it poses no public health risk if left undisturbed.

Construction of the new Perth Stadium on this site will pose significant problems for the site. Earthworks and excavations will need to be carefully managed to ensure safety of both the contractors working on site and any members of the general public in the area as well. It will also lead to environmental issues, as the proper disposal of such hazardous waste will pose a problem.

The state of the soil will also affect the geotechnical conditions of the site and in turn affect the way in which the foundations are designed for the stadium. This will all lead to a significant increase in the capital cost for the required preliminary construction works, and has the potential to dramatically impact on the budget of the project once construction has begun.

In addition, the Burswood Peninsula was originally mudflats with a series of sand bar islands. The present day form of the area is the result of infilling and river bank works in the Burswood Peninsula. Geotechnical stability issues with the site itself have been addressed in the past, as the existing structures in the area such as the State Tennis Centre and the Crown Casino Complex have been constructed in the area. Geotechnical shortcomings of the site can be addresses with the use of ground treatments such as placement of surcharge loadings and vertical drains to accelerate settlement within the area. The stadium structure itself will likely need to be supported by a series of deep piles (similar to a number of nearby residential towers) to the depth of the Guilford Formation, a dense layer of bedrock below the Burswood Peninsula (Department of Sport and Recreation 2012b).

Despite all these apparent issues and the shortcomings of the site, the Burswood Peninsula was still selected as the site of the new stadium. Whether this is politically motivated, the right move for the stadium or simply poor planning & decision making is still a matter of personal opinion and contention within the Perth community. However due to the lengthy process that has already been undertaken to reach this stage of a potential new stadium, the public opinion tends to be favouring a generally positive response and reception to the site selection.

6.7 Environmental impact

During the preparation of the Preliminary Project Plan, environmental characteristics of the proposed precinct were investigated through desktop environmental assessments, a preliminary site investigation, a sampling & analysis plan and a flora and fauna survey.

The results of the investigations revealed that the major environmental concerns to be considered on the Burswood Peninsula are mainly associated with the contamination of the site due to the previous/historical land usage. The landfill depths at the site have in the past been discovered to be as deep as 8 metres in some sections

The flora and fauna survey of the site and the existing Burswood Public Golf Course have identified a number of protected species of bird in the area, specifically the Carnaby's Cockatoo and migratory birds. There is no native vegetation in the area that has a classification of a protective species, nor are there any exotic introduced species that have protected status within the Burswood Peninsula.

The status of the protected species of birds was however not considered an impediment to the new development of the Perth Stadium Precinct in the Burswood Peninsula area, as has been the outcome of discussions with the Environmental Protection Authority.

6.8 Transportation issues

The Burswood Peninsula is currently subject to servicing by major roads, rail and bus routes. However, this existing transportation servicing is far from adequate to support 60,000 to 70,000 spectators in a timely and efficient manner.

This problem was identified early in the project definition as one of the potential drawbacks of the site. In response, a multi-modal transport strategy has been developed, with limited on-site parking but a high emphasis on public transport and extensive public parking facilities in the nearby East Perth region and Perth CBD area.

The main elements of the public strategy include the following aspects.

6.8.1 Rail

It is estimated that approximately 59% of patrons could be transported away from the stadium by rail within the first hour, utilising nearby Belmont Park Train Station that has been upgraded, and the existing East Perth Train Station further away.

Belmont Park Train Station is presently a single platform station. The transport strategy has identified significant upgrades to the station, including upgrading to a three platform facility, with the capability of accommodating a nine car train for approximately 28,000 people.

The East Perth Train Station is within a 25 minute walk to the stadium, with the potential to attract up to 7,500 people mainly travelling directly in a south or east direction that will not have to contend with transfers at the Perth City Train Station.

6.8.2 Bus

A bus service for events is proposed to service suburbs that are not serviced or accessible by rail. An estimated 120 buses would contribute to this service, accommodating up to 8,200 expected patrons. A major traffic study has indicated that the volume of traffic generated by the stadium will not warrant major road upgrades as most patrons are expected to utilise public transport to the stadium. However road improvements such as roundabouts and the upgrade of intersections near the stadium and casino would be beneficial to the traffic flow in the area.

6.8.3 Parking

It is expected that parking at the stadium and in immediate surrounding areas will be very limited as an emphasis is placed on the use of public transport to the stadium itself. Parking for emergency services vehicles, stadium operations, staff and associated visitors ix expected to be limited to around 250 within the stadium itself, and only an additional 700 bays within the sporting precinct surrounding the stadium.

There is an expectancy that around 20,000 spectators will source parking in additional surrounding areas outside the sporting precinct, such as car parks within East Perth or the Perth CBD and then walk to the stadium. Averaging 2.5 persons per car, this would lead to a requirement of about 8,000 parking bays. An investigation by the Department of Planning identified that there would be around 40,000 car bays in the surrounding areas of the stadium, which illustrates the magnitude of the supply of parking bays and that there should be more than sufficient car parking facilities to accommodate this demand.

6.8.4 Pedestrians

A major analysis of the distribution of spectators from the stadium was undertaken as part of the Project Definition Plan. Figure 6.4 and Figure 6.5 shows a Ped-Shed analysis (walkable catchment area) of the proposed stadium on the Burswood Peninsula. Figure 6.4 takes into account the existing arrangement, while Figure 6.5 includes a proposed new footbridge over the river, connecting the Burswood Peninsula to East Perth. The colours indicate the distance a person will walk from the stadium at 5 minute intervals. Comparison of the two analyses highlights the benefits of constructing a pedestrian footbridge over the Swan River to accommodate spectators and boost the number of patrons heading to the CBD and improve the local economy including at bars and restaurants in the vicinity.

The proposed footbridge will also minimise the impact on the existing East Perth residential area as it will not act as a thoroughfare like it were to be should the bridge not be constructed. It also provides an opportunity to create linkages between the existing pedestrian and cycling networks in the East Perth and Burswood Peninsula areas.

The analysis can also apply for spectators heading to the stadium prior to the event, and the benefits of the footbridge can be seen here as well for any people utilising parking in East Perth or the CBD, or catching public transport to the CBD and walking across.

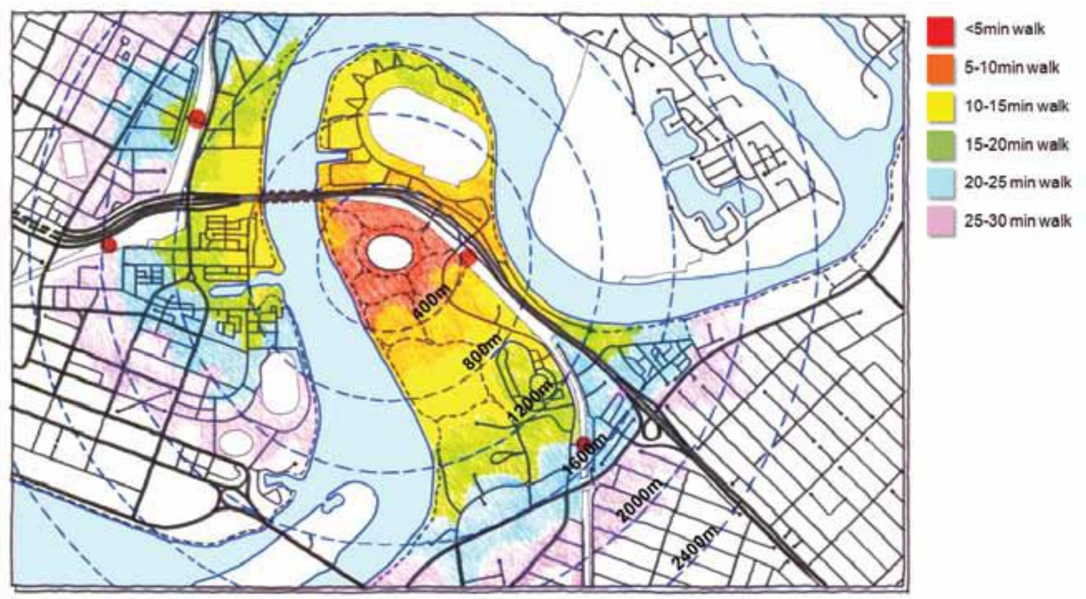

Figure 6.4: Ped-Shed Analysis of the new Perth Stadium - proposed footbridge not included (Department of Sport and Recreation 2012b)

Figure 6.5: Ped-Shed Analysis of the new Perth Stadium - proposed footbridge included (Department of Sport and Recreation 2012b)

6.9 Social and economic issues

By moving the location of the major stadium within Perth, the economic benefits of such a stadium to the local community also move with that. At the existing stadium in Subiaco, the numerous bars, restaurants and businesses all greatly benefit economically from the influx of patrons to the area on match days.

During the AFL finals series in September of 2013, businesses benefitted immensely from the patrons from the nearby Subiaco Oval and the joviality that followed the associated match wins of the local team. Some businesses in the area estimate that at least 30% of their income is owed to the draw of these big-ticket games (Preston 2013), and with Subiaco Oval set to cease as a destination for national sporting events such as the AFL, many businesses will need to turn to different tactics to try and recoup the inevitable loss of income that will follow.

Conversely, with the addition of the new Perth Stadium on the Burswood Peninsula, local businesses will receive expectant trade increases during event days. For some, it means businesses on the other side of the pedestrian bridge near East Perth and the Perth CBD will be benefitted from this relocation. The main beneficiary however will most likely be the nearby Crown Casino and Entertainment complex on the Burswood Peninsula. During events, much of the crowd will be expected to disperse towards the complex to patronise the Casino as well as its many bars and restaurants. The unfortunate downside of this is the argument that the Casino will receive the economic benefits of the influx of patrons to the area, which is perhaps the last type of business that would need this kind of free foot traffic being funnelled through its doors as it can generate problems within society related to gambling addiction.

Local bars and restaurants may not necessarily receive much of the increase in trade during these times which is a disappointing aspect of the choice of location for the new Perth Stadium on the Burswood Peninsula.

In addition, the cost of the Stadium is expected to reach upwards of $1 billion, as shown in Table 6.2. Of this required capital, the majority of this funding will be from the state government, with some from organisations such as the AFL and potentially the federal government, however none of this funding will come from the Burswood Casino or its owners, leaving the Australian taxpayers to foot the bill for the stadium whilst a business such as the Crown Casino and Entertainment Complex that will benefit immensely from this stadium is not contributing to the costs. This is a point of contention somewhat within the Perth community, as there is the potential for the overall costs to blow out and the funding for this will be expected to be sourced from other needy or worthwhile state government projects, hindering those projects and the overall finances of the state of Western Australia.

Table 6.2: Cost Plan Summary - Perth Stadium and Sports Precinct Works (Department of Sport and Recreation 2013)

Stadium and Sports Precinct Works	$'000 June 2011	$'000 Escalated
Base stadium & plaza	$382,588	
Fit-out & allowances	$103,202	
Consultancy fees	$60,036	
Margins & contingency	$144,167	
Stadium Works	**$690,000**	**$820,700**
Precinct pre-construction site works	$21,766	
Utilities & services	$19,115	
Precinct improvements	$29,335	
Sports Precinct Works	**$70,200**	**$81,700**
TOTAL WORKS COST	**$760,200**	**$902,400**

6.10 Sustainability focus

Though it is yet to be constructed, the new Perth Stadium will have a high focus on environmentally sustainable design. In a Project Brief Overview document released by the Department of Sport and Recreation (2013), the stadium is set to be 'a shining example of an efficient and sustainable sporting facility, befitting of a world-class stadium' (Department of Sport and Recreation 2013). As part of this efficient and sustainable stadium, it will incorporate the following design and construction features:

- A minimal impact on the surrounding environment during construction and ongoing operation.
- Promotion of efficiency in its design.
- Minimisation of greenhouse gas and carbon emissions, waste generation and water consumption.

- Provision of avenues for expansion in the future.
- Reduction of dependency of vehicles by providing extensive facilities for pedestrians, cyclists and public transport.
- Minimisation of energy consumption throughout the construction process as well as the ongoing operational processes through the use of natural light, natural ventilation, solar energy and low energy fixtures.
- Maximisation of recycling during both construction and operation.

Whilst it is too early to evaluate all of these options in a case study as the stadium is yet to be constructed, following the examples of stadia such as the Barclays Center in Brooklyn (see Section 5.9.3) in its sustainability focus will put the new Perth Stadium in good stead for such a high focus on sustainable construction and operations aspects.

6.11 Conclusion

The new stadium for Perth in Western Australia will be an example of stadia innovation and a tribute to the evolution of stadia through its incorporation and inclusion of many features that have arisen from the developing needs of stadia around the world.

Though the project is still in its infancy and is presently in the pre-construction phase, it has still come a long way from inception, and still has a long way to go, including the construction of the stadium itself.

Whether the stadium is to be built in the right location for the City of Perth itself is still a point of contention, however it is now a moot point as the decision has been made to construct the stadium on the Burswood Peninsula and progress has been made to realising this achievement.

7. Chapter Seven: Conclusion

7.1 Introduction

Stadia design and construction has evolved immensely throughout history. From the origins as simply grass fields with hill embankments, to technological wonders such as the Barclays Center in Brooklyn or the soon to be constructed Perth Stadium in Perth, Western Australia, these stadia have benefitted from the years of identification of mistakes, errors, points of excellence or the ever-changing needs of society.

The rise of television, technology and communications has brought with it an exponential interest in professional sports and the viewing of such events that captivate so many around the world, and this has brought stadia design to the forefront of engineering and architectural innovation. While there is still a global fascination with building the tallest and most unique skyscrapers and structures imaginable, the desire to compete with the likes of stadium structures is rapidly gaining momentum, especially within the last decade. They are a source of pride for countries and their citizens, and as such are becoming the highlights of urban landscapes around the world.

7.2 Conclusions

Looking towards the future of stadia design and construction, there will inevitably be an even more intense focus on sustainability and environmentally sensitive design, construction and stadium operation.

There is also an apparent and likely future focus on a portable or modular stadia system. With the rise of global sporting events such as the FIFA World Cup or the Olympic Games, there is a rising need to find a solution for the use of stadia at the conclusion of these events. These stadia are typically purpose built for these large events, however many receive only a fraction of the use or spectator crowds that were being experienced during those events.

In South Africa for example, the end of the 2010 FIFA World Cup Tournament signalled the end of use for the Peter Mokada Stadium and the Mbombela Stadium. No contingency plans had been established for these stadia, and they face an uncertain future as organisers and the government attempt to secure a financially viable future for the 40,000-seater stadiums in areas already blighted by poverty and anti-social issues.

To solve problems such as this, architects and engineers are already starting to engage in this theory, and develop concepts for modular or pre-fabricated stadia. The idea behind such a concept is one of two ideologies:

a) Construct a core structure of (for example) a 25,000 seat stadium. Modular seating developed for this stadium would have the ability to increase the capacity up to 80,000 (as an example) for a large event such as the FIFA World Cup or Olympic Games. At the conclusion of the event, the modular seating could be disassembled and removed, leaving a sustainable stadium as its legacy.
b) Construct modular stadiums from scratch using prefabricated techniques. At the conclusion of the event, the entire modular stadium could be taken down and transported all over the world to another event in another country.

This is where many prominent architects and engineers in the stadium design and construction fields see the future of the industry. In addition, examination of every material and design aspect from a sustainability point of view during the initial planning and design phases with the view that everything should be lightweight, recyclable or locally sourced whenever possible is a direction that we are headed in.

The benefit of such a future with modular or portable stadia also aides countries with a traditionally lower GDP (such as some 'emerging nations') to bid and attempt to win the rights to host such a global event. The ability to source portable or modular stadia to satisfy events can in turn bring countless economic benefits, mainly from tourism during the event, whilst reducing the required up-front costs for such associated stadia infrastructure.

The future direction of stadia is shaped by those involved with stadia design, construction and operation. It is only once they have a proper understanding of where these design and construction aspects have evolved from and the reasons why they have done so that they can fully appreciate stadia and the direction that it is needed to head in the future in order to meet with the expectations, requirements and aspirations of society today. The importance of stadia in this society cannot be understated, and sports and leisure and by extension the associated infrastructure such as stadia faces a defining period in its history.

7.3 Further Research and Recommendations

An appreciation and understanding of stadia should now be obtained having studied this dissertation document. The dissertation generally covers the history of stadia and gives a clear but concise overview of the progress that has been made over centuries of stadia structures.

In order to properly understand the future direction, the reader is recommended to conduct their own further research and work on the topic. Further research into published literature on modular and portable stadia is recommended to enhance the reader's perception of the future of stadia development. Though there is presently limited information on the subject, further research in this field will inevitably be published as the focus of stadia design and construction turns to sustainable stadia and how modular stadia can achieve this goal. It would also be advantageous to research issues associated with the construction of large stadia, such as the development of rainclouds within the stadia due to the mini-atmosphere that can be created by a large stadium.

Further readings are also recommended on topics such as the 2022 FIFA World Cup in Qatar, where there is a strong focus for environmentally sustainable stadia that can also be dismantled at the conclusion of the event and transported to countries all over the world that require such infrastructure. Further research into this topic or similar theories would be extremely beneficial to the reader for the topic of stadia design and construction.

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Appendix A. Project Specification

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111/4112 Research Project

PROJECT SPECIFICATION

STUDENT: Brett Jenaway

TOPIC: Evolution of stadiums: A study of design and construction of ancient and modern stadia

SUPERVISOR: Mr Paul Tilley

ENROLMENT: ENG4111 – Semester 1, 2013 (External)

ENG4112 – Semester 2, 2013 (External)

COURSE: Bachelor of Engineering

MAJOR: Civil

PROJECT AIM: This project aims to investigate the ancient and modern methodologies of stadium design & construction, with a focus on modern innovations and requirements that are becoming the mainstay of stadiums in design and construction around the world, and the factors that influence these engineering innovations. Evolution of stadium design will also be examined by analysing ancient stadium design, and the progressive stadiums and designs over history that has led to modern designs and innovations.

PROGRAMME: (Issue B, 21 March 2013)

1. Research the background and origin of stadiums in Ancient Greece (used for the ancient Olympic Games) and Ancient Rome (the Colosseum).
2. Explore and evaluate the designs and construction methods used in these structures (such as ancient

Roman concreting methods or structural support systems such as Voussoir arches).

3. Bridge the gap between ancient and modern stadiums; that is, explore the evolution that occurred to these designs over the past few thousand years, and what early or ancient design aspects and considerations are still being used in modern stadium design & construction today.
4. Define modern stadiums uses and main factors taken into consideration during the design phase (primarily) as well as the construction phase.
5. Explore the requirements for site selection in terms of geotechnical analysis and engineering, with respect to suitable and unsuitable potential sites (such as on a river front or a landfill site).
6. Analyse the role that various construction materials (such as concrete, steel and high strength steel) play in design and construction considerations.
7. Research and evaluate various structural systems for stadium roofing (including retractable structures, cantilever structures, column & beam arrangements and membrane structures).
8. Case study of future new stadium in Perth, Western Australia. Analysis of site selections, engineering considerations, social-economic factors, advantages and disadvantages of various options touted in the media (and by the state government's stadium task force which has identified a number of main potential options).
9. Explore various modern engineering innovations at recently conducted stadiums. Possible avenues of

research: membranes structures at Allianz Arena in Munich and National Aquatics Centre in Beijing; cantilever support structure at Wembley Stadium in London.

10. Preliminary design of roof & support system for case study of future new stadium in Perth, Western Australia.
11. Analysis of current major stadium in Perth – Subiaco Oval (or now formally known as Paterson's Stadium) involving a site visit and tour of facilities, and analysing the limitations and possible issues with redevelopment of this stadium from an engineering perspective.

As time permits:

12. Exploration of the future of stadium design – perspective on what the future could hold for stadium engineering in terms of design and construction, as influenced by advancements in technology.
13. Investigation into the sustainability of modern stadiums, and the processes and ideas that have been implemented into the construction and functionality of these stadiums to increase sustainability and "go green".

PROJECT SPECIFICATION AGREED

Student:

Name: ______________________ Signed: ________________________ Date: _____ /_____ / _____

Supervisor:

Name: ______________________ Signed: ________________________ Date: _____ /_____ / _____

Examiner/Co-examiner:

Name: ______________________ Signed: ________________________ Date: _____ /_____ / _____

Appendix B. Ideal Stadia Viewing Positions

Preferred or ideal viewing positions for some of the world's predominant sports

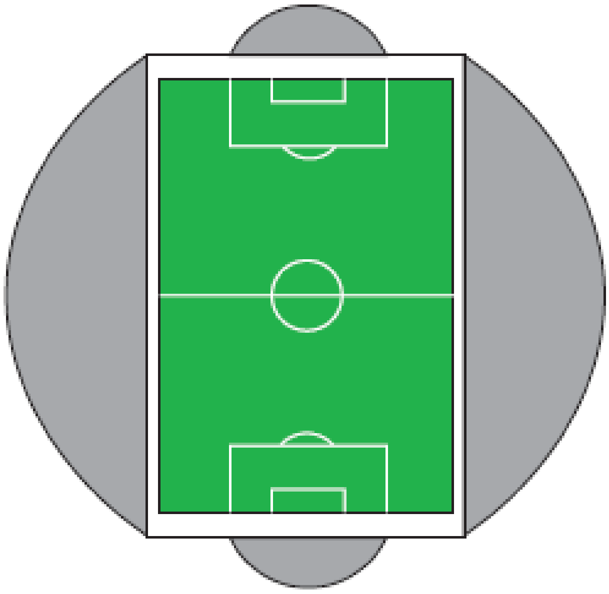

Figure B.1: Football (Soccer)

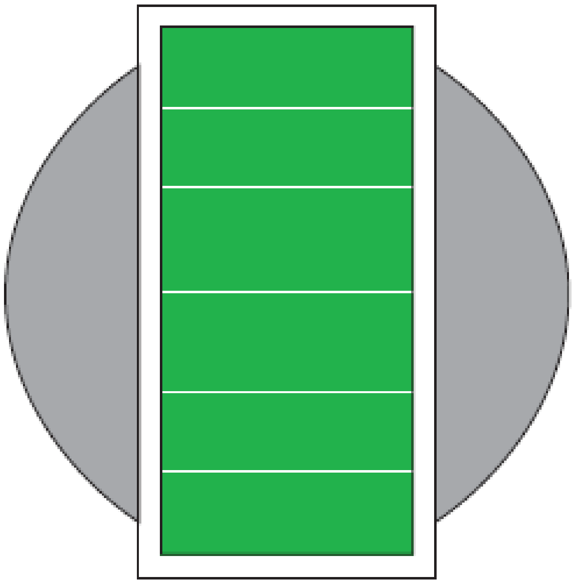

Figure B.2: American Football (Gridiron/NFL)

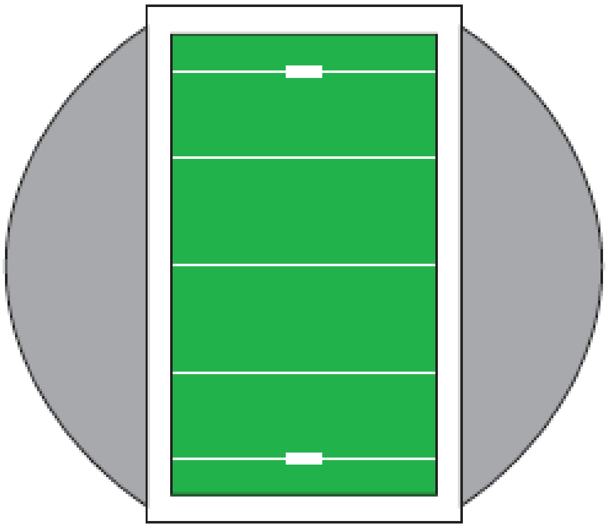

Figure B.3: Rugby League and Rugby Union

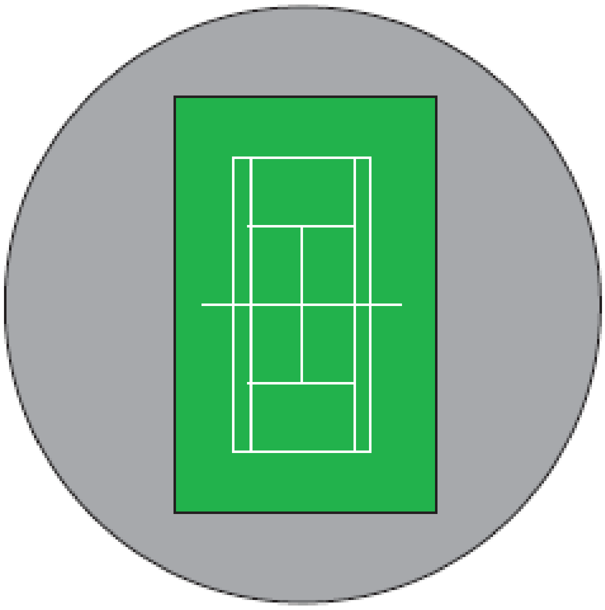

Figure B.4: Tennis

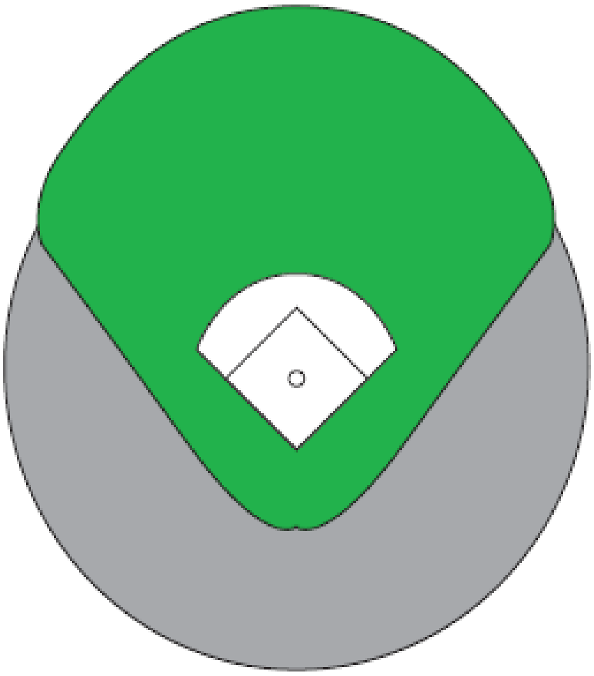

Figure B.5: Baseball

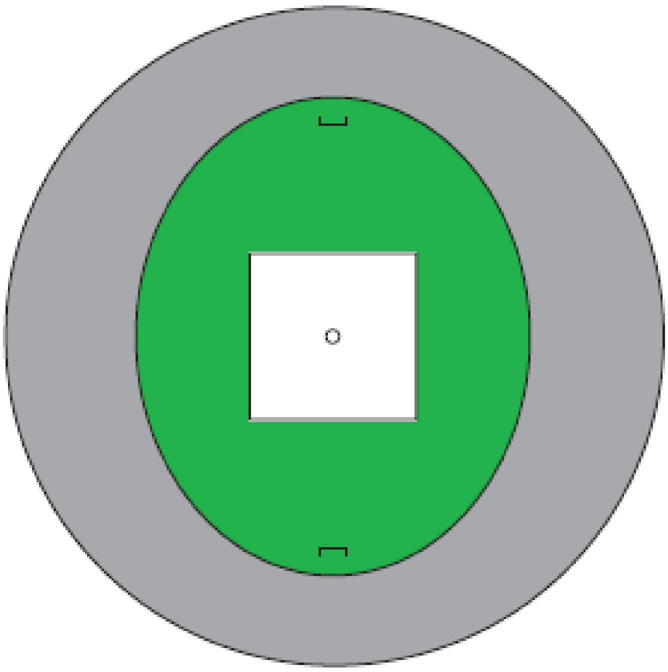

Figure B.6: Australian Football (AFL)