OPTIMISATION FOR SPORT STADIUM DESIGNS

Advantages for shifting from macro level to micro level viewing optimisation in stadium design

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Abstract. Applying computational optimisation tools for sport stadium designs has become common practice. However, optimizations often occur only on a macro level (analysing stadium as a whole) and not on a micro level (a view from each seat). Consequently, items on a micro level with design details like guardrails can be overlooked, leading to financial losses for operators. Hence, the research argues that every seat is encouraged to have a clear field of view to avoid financial complications. In order to address this problem the research team developed and evaluated a script that allowed importing an existing design into Rhino. Firstly, the script evaluates the view of each seat via a colour coded response system. Secondly, the designer can select the respective seat, and view the sightline from the occupant’s sightline to various spots on the field to analyse where the obstruction is occurring. This ‘binocular view’ enables the designer to evaluate blind spots from each seat prior to project completion. As the script allows the designer to automate the micro level analysis, the research arguably provides a significant improvement for stadium design by comparing the time used for a design optimisation in a conventional method with the automated one.

Keywords. Stadium design; Design optimisation; Design analysis; Customised software development; Grasshopper scripting.
1. Introduction and outlining problem

Applying computational optimisation tools for sport stadium designs has become common practice. Most current stadium designs now use parametric design tools for optimisation of two main aspects in stadium design – maximising number of seats and improving views to the sports ground. It is evident that a larger seating capacity within a venue will provide greater profits and poorly positioned seating can cause problems, such as poor reputation for the venue and significant financial loss over a prolonged period of time. However, optimizations often occur only on a macro level (analysing stadium as a whole) and not on a micro level (a view from each seat).

To give one example, the Investors Group Stadium, home to the Winnipeg Blue Bombers in the Canadian Football League, has experienced several problems with obstructed views due to higher guard railings in certain sections. This has forced the venue to offer ‘50% Off’ affected seats in order to correct this issue (Penton, 2012). This case study outlines a viewing obstruction that could be easily overlooked when optimising a stadium design on a macro level. Using this example as a precedent study for further research in the field of stadium seating design, it is clear the positioning poses a substantial long-term financial issue for the respective venue.

Consequently, items on a micro level with design details like guardrails can be overlooked, or a detailed analysis can be completed only through a time-consuming analysis as opposed to an automated process. As it is paramount and defined by governmental regulation to ensure that each seat within a venue has a clear field of view to avoid complications surfacing (DCMS 2008, pp108), traditional design firms often choose a time consuming manual analysis to assure their stadium design meets the required results and expectations of clients and regulators like FIFA.

2. Research Question

Observations as listed above were evidence of ignoring individual seat viewing angles have led to financial loss as demonstrated in the Investors Group Stadium example demonstrated and interviews with the industry partner Cox Architects, Sydney. Hence, the research argues that it is important to ensure that every seat has a clear field of view to avoid complications from arising, thus arguing for the need and raises a research question to:

“Can, through the development of an individual seat optimisation, software detect obstructions on a micro level in order to avoid unwilling blind spots which leads to financial losses and to guarantee an optimise view to the grounds for each spectator in the stadium?”
3. Methodology

Drawing on existing knowledge on stadium design such as ‘Stadia: A design and development guide’ (John, et. al, 2007); New York Yankees – How to avoid obstructed views’ (Smith, 2008) or ‘Stadia, Arenas and Grandstands: Design, Construction and Operations’ (Thompson, et. al, 1998) and guidelines in particular ‘Football Stadiums – Technical recommendations and requirements’ (FIFA, 2007) and ‘UEFA Guide to Quality Stadiums’ (UEFA, 2011) the discussed software development applies action research and user-centered design as an overarching method for the development of the case studies. In order to answer the key research question, a series of test scripts where developed in order to evaluate the view of each seat via a colour coded response system. In the second step of the development, the designers were able to select the respective seat, and view the sightline from the user to various spots on the field to analyse where the obstruction is occurring. This ‘binocular view’ allowed the designer to witness the affected areas from the seats perspective prior to project completion.

4. Background research

It can be argued that a stadium’s success is dependent upon several factors, primarily the spectator’s individual ability to view the event unhindered by obstructions. Although it is clear that organized seating within stadiums has allowed for thousands to experience key sporting events in a live setting, there is a stark difference in designing effective seating as opposed to creating an ineffectual seating plan. It is palpable that a well-arranged seating layout can essentially accommodate more spectators. Furthermore, arranged seating has consequently allowed for spectators to be granted an enhanced view of the field of play. This augments public opinion, and in turn, can potentially create a surplus of finance for the venue. Hence, it can be stated that several factors need to be taken into consideration when designing an effective stadium-seating layout. These include the following:

Field Of View / View Obstructions. The field of view is defined as the area of the field visible to each and every spectator within a stadium (Wikipedia, 2014). The ability for a spectator to be able to see the entire field of play is imperative to a stadium’s long-term success, and the driving factor in creating effecting venue seating. UEFA Guide to Quality Stadiums (2011) states that all spectators should have an unobstructed and complete view. This safeguards the notion that all spectators will be satisfied watching the event from their seat, ensuring the success of the venue.

Sightlines / C Value. Sightlines can be delineated as a hypothetical unobstructed line from an individual’s eye to the focus point, predominantly field
of play (Oxford Dictionary, 2010). It is important to ensure that a spectator’s ability to see the field is not hindered. Thus, in order to calculate this viewing distance, a mathematical formula known as ‘C Values’ is used. The C Value is the vertical distance from a spectator’s eyes to the sightline of the spectator directly behind them (Wikipedia, 2014). According to the UEFA Guide to Quality Stadiums (2011), the optimum C Values range ranges of 9-12cm; the bare minimum value set at 6cm. The formula to calculate this is:

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

(1)

Where C equals: D = the horizontal distance from the eye to the point of focus; N = the riser height; R = the vertical height to the point of focus; and T = the seating row depth.

Seating Bowl Rake. The C-Value is used to help produce a seating bowl rake (Pickard, 2002). The Rake can be defined as the curve in which the stadium seating follows. It is calculated through using the riser height values, which are taken from the C-Values equation (Ibid). If the rake is produced correctly, the overall curve will follow half a parabola when one views it through a section (Ibid). As the rake increases in height, it is evident that the curve becomes steeper to ensure each row can see over the respective spectators in front of them. It is essential to also note that the seats closest to the field are often the most sensitive to the impact of the C-Value due to their low angle of incline towards the sideline on the field (DCMS, 2008). According to the UEFA Guide to Quality Stadiums (2011), every stadium bowl should consist of the three principles of safety, comfort and visibility. Within modern stadiums it is expected that each spectator should be able to obtain food and beverages with minimum fuss. It is pivotal that the stadium bowl be designed to enable easy movement in and out of seating rows, as well as provide a ‘quick and simple’ passage from the seating area to amenities and catering facilities (Ibid). Also, the bowl should not be designed too large of an incline, to ensure problems of vertical positioning do not occur.

Vertical Positioning. It can be argued that a stadium’s seating incline should be calculated to a suitable degree for several reasons. Firstly, a spectator’s respective ability to successfully view the entire field of play is one of the greatest concerns when designing venue seating. It is evident that the vertical design of the stadium bowl should be consistent with the purpose of the venue. For example, a stadium which hosts sports such as cricket or tennis, require spectators to be able to follow the motion of a small ball around the field. By designing stadium seating too high, spectators can potentially be disadvantaged in watching the sport at the particular venue. Pickard (2002) generally accepted that an angle of rake steeper than 34 degrees is considered uncomfortable, and induces a sense of vertigo.
**Viewing Distance.** It is evident that the human eye struggles to perceive anything that subtends an angle less than about 0.4 degrees, especially a rapidly moving object such as a ball during an event (John, et. al, 2010). Thus, the preferred viewing distance will vary from sport to sport. For example, a rugby or soccer ball (approx. 250mm in diameter) sets the preferred viewing distance from the spectator’s eye to the extreme corner of the field at 150m, with an absolute maximum distance of 190m (Ibid). In relation to tennis, (Ball 75mm in diameter), the preferred viewing distance reduces to approximately 30 metres (Ibid).

**Comfort.** The comfort of spectators can be an influential factor in a stadiums overall success. Thus, it is essential that comfort be a driving factor in the design phase of seating design. The *UEFA Stadium infrastructure regulations* (2010) specify that all seating for spectators must be ‘individual, fixed seats (to the floor) which are all separated from each other and regulations ask for a min. backrest (h = 30cm) from seating platform base (Ibid).

**Safety.** Above all else, the most important factor in any venue’s subsequent construction is the safety of all those within the given structure. It is apparent that stadiums must pass several inspections before they can be used, including a stadium capacity check by the respective authorities. In regards to football, the maximum safe capacity of a venue must be checked to ensure stadium overcrowding is not an inherent issue (UEFA 2011). It is evident that are several factors which must be checked, such as: the holding capacity; the entry and exit capacity; the emergency evaluation capacity; and final holding capacity.

5. **Case study / Software development**

The brief for the investigation started with a discussion with the industry partner who wanted to input a 3D model of their desired stadium into Rhinoceros. For them the script would then examine the geometry contained within the stadium file to analyse the sight obstructions from any given seat, while respecting the above, in the background research listed criteria. For the research team this essentially resulted in creating a plug in script for Grasshopper, in order to potentially save the firm several hours in both the design and analysis of a project. Further, the script would have to contain several features, including the ability to identify which seats had better sightlines towards both the field of play and the scoreboards. By doing so, one could calculate which seats were considered in the premium range, and thus increase profits whilst improving public opinion towards a venue.
5.1. CREATION OF THE BASIC GEOMETRY

In order to create a Grasshopper script to analyse stadium seating, it was agreed that a set of dummy geometry would be required to develop the initial analysis process. Using the measurements obtained in the FIFA standards, a basic stadium seat was created through the use of several different scripting nodes. Although the stadium seat was complete, it was evident that a basic dummy torso and head would be needed to ensure that an analysis could be created. By once again, using combining several geometric nodes, a torso and head were composed. According to the Australian Bureau of Statistics (2011), the average height of an individual in 2011-2012 in Australia was concluded to be 175cm (5 feet 9 inches), and thus this measurement was used to create the desired geometry. In order for analysis to be created at a later date, it was important to also model the fence separating the field from the grandstand. According to the FIFA Standards (2007), the fence between the grandstand and field of play should not exceed h = 1.25m. As it was witnessed through the case studies provided, many sight obstructions within stadiums often occur due to railings. Thus, by modelling the grandstand fence to exact dimensions, an analysis with a higher rate of validity could potentially be achieved, significantly enhancing the project’s end result.

5.2. CREATION OF THE SEATING BOWL

During the research phase of the project, it became clear that stadium bowls use a complex mathematical algorithm known as the C Values. As previously mentioned, the seating rake follows the shape of a semi parabola, allowing each person to see over the other spectators in front of them. At present, the common method to calculate sightlines within a seated venue is through the use of a two dimensional diagram, focussing on a side on perspective of an individual’s ability to view the field of play along a diagonal plane. However, this method does not take into account a person’s ability to look diagonally, thus presenting a significant flaw in the current technique. Although the C Values formula appeared quite straightforward, the challenge was to use this formula to create geometry on the required curve. Before the script could be written, much time needed to be spent to ensure the correct data would be produced. Additionally, by calculating each individual riser height, it would allow for a referral point during testing. With the help of skilled programmer, a starting point for the visual basic script was articulated, producing the required data into a table format for easy viewing. Further scripting was then produced to link these measurements with each respective riser, allowing for an array of a curved geometric seating curve to be achieved.
5.3. INITIAL COLOUR ANALYSIS

The inherent ability to analyse collected data from a three dimensional model was vital to the success of the project. By collecting and displaying the gathered data, it would potentially allow a user to view the current geometry and be informed of flaws with the current design. Although a program to collect data has its merits, its significance lies in the ability to display the required information in a clear and concise way for its subsequent users. Thus, using colour to create parameters would allow for the Grasshopper script to not only become more appealing to new users, but improve the speed in which results could be interpreted. In a first attempt to use colour to analyse data, a basic script was formulated using a gradient node and an attractor point. This allowed for the objects close to the attractor point to be projected in the colour green, whilst the geometry progressed to red as it moved further away. This first use of colour provided the initial steps towards a more successful script in future weeks.

5.4. INITIAL PROXIMITY ANALYSIS

During the early stages of the design process it was agreed that, in order to produce an effective Grasshopper script to calculate obstructed views, a method would first have to be selected to achieve these results. It was established that only conceivable way of achieving this would be to create an analysis through proximity between two objects. Through the development of a script, which projected IsoVist rays from a starting point, all obstructions would be identified through the lengths of each visible line. In essence, the script subtracted the length toward the obstructive geometry from the original set length to provide an analytical view. By creating a script that allowed for an object to be identified as an obstruction, it provided the ability to collaborate the created geometry. By selecting the model of a person’s head, it allowed for a calculation of the projected distance between one’s eyes and the field, identifying all visible obstructions.

5.5. COMBINING COLOUR WITH PROXIMITY

Although both colour and proximity had proven to be quite useful individually, the notion to combine the two works into a new formulated analysis script was conceived, providing much success towards the overall progression of the project. By using green to display a clear field of view between a person’s eyes and the field, whilst using red to display obstructed views, the script had allowed for a clear distinction. By conveying the affected seats in a different colour to the unaffected areas, it allowed for a fast, conclusive
partition between seats. This in turn, allowed for the idea to be progressed even further.

5.6. A PROGRESSION IN COLOUR

Following a meeting with the industry partner, it was made clear that a larger distinction would need to be created, thus asking for a next iteration. In reality, a stadium designer would need to identify which seats were more affected than others, and thus the current script only essentially separated the best good seats from any containing a partial or complete obstruction. By using a gradient node along with several other complex functions, a field was able to be constructed. By then dividing it into squared metres and connecting each square’s centre point to the eyes of a spectator, a larger distinction was achieved, defining seats in accordance to the amount of blockages each seat respectively experienced; green displayed obstructions equalling 0-10% of total views from an individual seat, the colour chartreuse defining 11-20% of blocked views, yellow showing 21-30%, orange displaying 31-40% and lastly, red defining any obstruction between 41-100% of the overall view.

5.7. HORSTER CAMERA

Through discussion with industry partner, the idea to create an individual camera for each seat was conceived as a last iteration of the project. This
was achieved through the Grasshopper plug-in known as ‘Horster’. This new directive permitted a user to select an individual seat within a grandstand, and in turn view the field of play from that respective vision point. This would allow a designer to fully comprehend the extent to which an obstructed view would affect the experience of a spectator sitting there. Furthermore, the plug-in permits the ability to move the focus point, creating the sensation of following the play around a field during an event.

6. Evaluation

Despite the intrepid attempts to step beyond the constraints of previous knowledge and endeavour towards an unprecedented creation, the project fell short for a variety of reasons. Firstly, with the thirteen-week time frame (length of a semester) to create an immense program from such an infinitesimal beginning, it is plausible to note only a foundational research could be achieved; the task of formulating a grasshopper script to perform functions, which collectively do not currently exist was convoluted. Thus, any progress towards a future working program could be considered instrumental achievement in the allotted time. Despite the inability to complete the aimed overall program, it is evident that the progression of script thus far is still able to provide an answer to the proposed research question, of whether the development of an individual seat optimization program would be successful in detecting obstructions on a micro level in the pursuit of optimizing views within a venue. It was evident through the development of the script, that Grasshopper offers many options to create a successful analysis tool. Through the use of colour and proximity, a script was formulated which undoubtedly demonstrated Grasshopper’s prowess for both design and analysis. It is indubitable that a tool of this nature can be used to detect obstructions at the micro level of seating within a venue.

7. Significance of research

It could be demonstrated that the research provides many opportunities as a tool to analyse pre-existing stadium structures and provide a significant improvement for stadium design by reducing the time used for a viewing optimisation when comparing a conventional method with our automated one.

Despite the inability to complete the research to the originally desired level of accomplishment, it is clear that in its completed state as a standalone program, which offered various forms of analysis; this script presents a method of optimising stadiums in a micro level and thus help designer to avoid unpleasant surprises and financial consequences as listed in the Inves-
tors Group Stadium. Further the script can be applied for projects where views to an area are crucial, such as movie theatres to conference centres.

8. Discussions and Conclusion

There were several other features on which upon the existing script could be improved as a next step. In our opinion the next phase, after completing a stand-alone program, would be to redirect the script to create a further parameter for analysing the prime positions of stadium scoreboards throughout a venue. Furthermore, it is palpable that the script could be also adapted to conduct a reverberation analysis within a stadium in order to measure the way in which sound travels. Sound is a further aspect that contributes highly to the experience of a stadium visit – a factor that has not been taken in consideration in this research. Consequently there are options to extend the script towards becoming a completely holistic program for stadium design.

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