The Controversy between the Human Factors and Ergonomics Demands and the Current Designing Rules of Contemporary Stadiums

Zdzislaw Pelczarski

Bialystok University of Technology, Bialystok, Poland
pelczarski.z@wp.pl

Abstract. The research concerns determining factors of the development of architectural form of modern stadiums and leads to conclusion that the size and shape of the field of game, which is the field of observation, is derivative of the game rules, with no any regard to the factors defining visual comfort of spectators. These game rules, having been invented over one hundred years ago, had not account for the entertaining character of the action on the pitch, nor for the need of co-existence between the field and huge spectator stands.

The interiors of future stadiums should be shaped considering correct relationship between the needs of spectators and arena. The appropriate standards of the visibility, adjusted to anatomical features of human eye perception, should have the supreme priority in these relationships, consequently causing, as an outcome of these corrected standards, changes in the shape and size of the arena.

Keywords: human factors, ergonomics, contemporary stadium, designing.

1 Introduction

The architectural form of contemporary stadiums is the result of evolutionary development lasting about a hundred years. The most important element that initiated this process was the playing field, in particular its size and shape. Rules of the Game, including the football pitch parameters, have been specified in the code known as the Cambridge Rules, which final version was established in 1863 at the University of Cambridge, shortly before the first meeting of The Football Association. These rules played a significant part in developing the contemporary football.

In the first paragraph of this document saved to establish that the length of the ground shall not be more than 150 yds. (137 m) and the breadth not more than 100 yds. (91 m). It was a field of game much larger than the rectangle with dimensions of 105 m x 68 m, required today by FIFA. Notable is the fact that the creators of the rules of the game have not took into account the huge number of fans who, like it soon turned out, became an inseparable and key part of the football phenomenon.

Already the first years after the creation of football league in England had proved that thousands of supporters of their club teams started to participate massively in all

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Fig. 1. Football match being played on Monkmoor Race-course in Shrewsbury. The match took place as part of the celebrations for Queen Victoria's Golden Jubilee in 1887. [Author: unknown, Document reference: PH/S/13/M/13, Shropshire Archives, Castle Gates, Shrewsbury, SY1 2AQ, http://www.archivezone.org.uk/subjects/sport-and-entertainment/f; admittance: 26.01.2014]

Fig. 2. Archive image shows match at the Fallowfield Ground in Manchester for the 1893 final between Wolves and Everton. Fallowfield had an official capacity of 15,000, but 45,000 turned up to watch. [Author: unknown, File in the Public Domain, Wikimedia Commons, http://en.wikipedia.org/wiki/File:FA_Cup_Final_1893_Wolves_Everton.jpg; admittance: 26.01.2014]

matches, including these played outside of their place of residence (Fig.1., Fig.2.). For example, over 114,000 people watched match Tottenham Hotspur versus Sheffield United in the 1901 Football Association (FA) Cup on Crystal Palace Stadium in London. It has been estimated that a large percentage of these football supporters travelled by the railways. In 1923 the FA Cup was moved to Wembley. The ground had

been built for the British Empire Exhibition and had excellent railway links. Over 270,000 people travelled in 145 special services to the final that featured West Ham United and Bolton. The facts, as reported above, show that already in the early stages of the football stadium development, it turned out, that as important as field and rules of the game are needs of numerous observers of the action ongoing on the arena. From that moment until today, the architects have focused attention mainly on the activities related to the enlargement and quality improvement of the spectators' zone - but adjusting it in the same time to the constant size and shape of the enormous playing field, defined by the rules of game in 19th century. Soon they realized however, that increasing the capacity of the stadium stands has strict limitations, caused by the anatomical range of vision of human eye.

A dominant influence on a form of the modern football stadiums have great world organizations, such as FIFA or UEFA. Acting in new reality of the commercial sport they define and control the utility standards, deciding about the minimum allowable values of their parameters. They also have an impact on regulations issued by the International Committee for Standardization. These standards are not always the result of a premise to ensure the highest operational parameters for the entire audience watching mach.

2 Limites of the Range of Human Sight

For the human eye the critical angle of seeing of two points as separate objects equals 0°1' (0,017°), [1]. European Standard EN 13200-1 specifies two values of maximum range of sight for soccer stadiums: 190m, as a maximum value and 150m, as recommended one [2]. In case of the first, angular height of the retinal image of soccer ball is ψ=0º4' (0,067°), what means only four time more than critical minimal angle of view. In case of the second one its value rises up to 0º5'. In consequence of these regulations the limited distance of farthest row of the audience to the farthest point of playing field is determined by calculating the distance at which the ball, is seen in the angular size equal to the minimum viewing angle (ψ). For the ball of soccer, with a diameter of 22 cm, this distance is 190m (Fig.3). The boundaries of the field for maximum range of view at football stadium is determined by drawing arc lines, which are a set of points in space behaving just this distance from each of the corners of the rectangular pitch (Fig.4.),[3]. This parameter determines the spatial size of the spectators' zone, its capacity and shape. This in turn translates into qualities of usability, communication and evacuation routes, as well as the construction cost of stadium stands and canopies.

3 Dependence of Size of Retinal Image on the Distance from the Observed Object

The size of retinal image is usually expressed in the angular value, as so called viewing angle. It is the angle between two rays of view running from the extreme points of

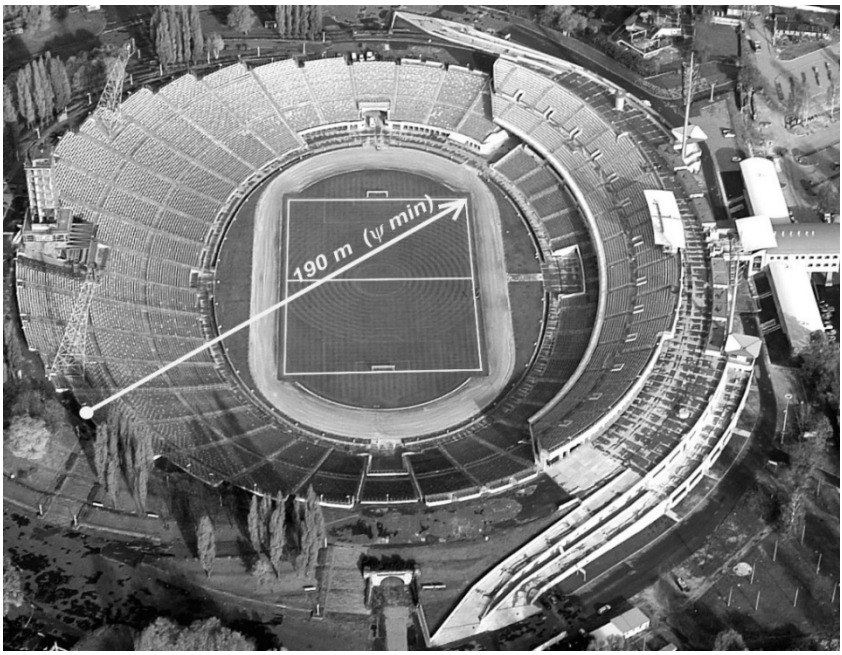

Fig. 3. The maximum range of vision of football (Lmax = 190m) determined by the elevation height of points of the eye in the top row and minimal angle of view of the ball (ψ = 0º4'). *Stadion Slaski* in Chorzow, Poland 2005; (photo: P. Oles, WOSiR Achieves)

the observed object, intersecting at the geometric center of the eye lens. Viewing angles decrease with increasing distance of the object from the eye of the observer (Fig.5., Fig.6.). As mentioned above the dynamics of changes in the size of the vertical viewing angle of a player figure depend on the distance from the observer. In zone of small distances (5-35m) occurs a sharp drop in angular height of retinal image of the object, from 20º to 3º (with average decline rate 0,57º/1m). In zone 35-100m can be noticed the reduction of this height is 3º to 1º (with average decline rate 0,03º/1m). Zone 100-190m is characterized by the decrease of height of image of observed object from 1° to 0.5° (average rate of decline 0.006°/1m) [4].

As shown in Fig.5. the largest distances between any place in the stands and the furthest point of the pitch are equal to longest lines of vision and the smallest viewing angles, achieved from this place. They are always lines of vision of the pitch furthest corner. For the first row of seats the shortest line of vision of furthest corner (Ls1) belongs to central place (Pe1) and is equal 90m. The longest sight lines (Ln) belong to points of eye lying on arc line with a radius of 190m with the center in the furthest corner of the pitch. It means that the angular heights of players figures seen on the pitch in these critical points (pitch corners) of field of vision for all the viewers, regardless of the place occupied, are in the range of very low values, such as 0,54° - 1,15°. This is due directly to the dimensions of the playing field, defining, in fact, the vast field of observation, which considerably exceeds the capabilities of the human eye in range of full and qualitatively satisfying visual perception.

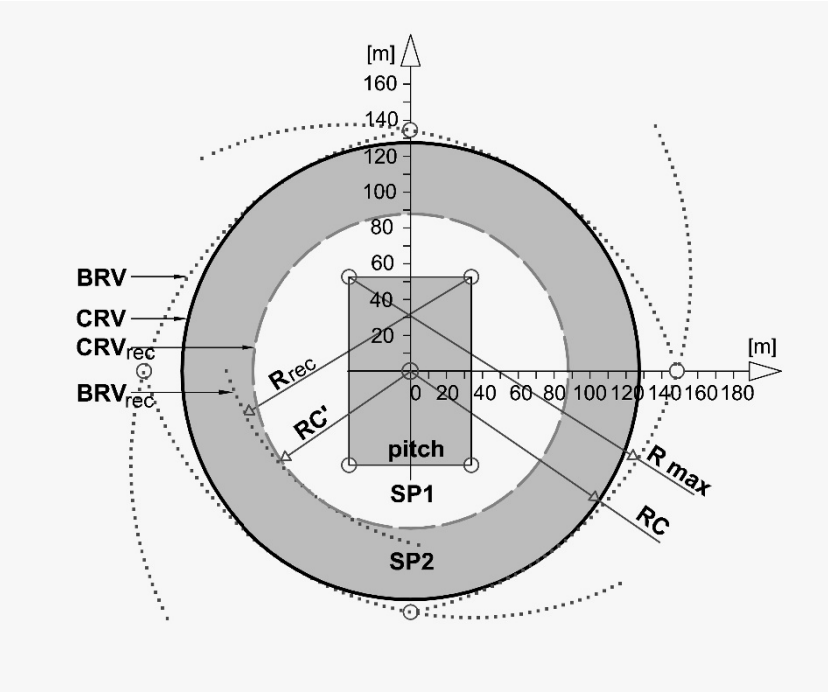

Fig. 4. Field of maximum range of view of the soccer pitch (according to the European Standard: EU-13200-1); R max = 190m, recommended: R rec = 150m; (author)

Legend:; *BRV=190m - Boundary of the field of maximum range of view of soccer pitch, angular height of a player αp = 0,54°*; *BRVrec =150m - Boundary of the field of recommended range of view, αp = 0,69°*

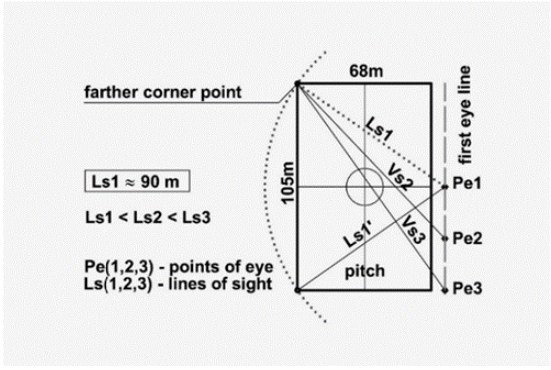

Fig. 5. Analysis of the view lines length from the first row of seats when observing the farthest corner of the playing field, (author)

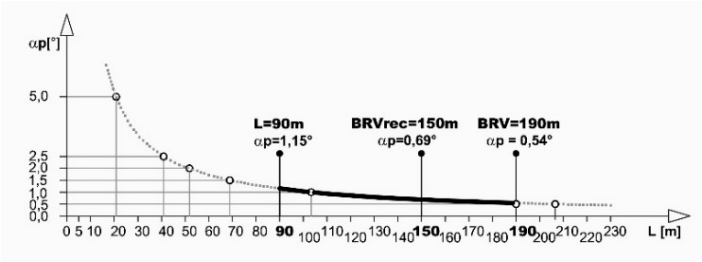

Fig. 6. Dependency graph of the angular height of the footballer on the distance of the observer; (author)

***Legend**:; **αp** –Angular height of a player; **L** -Distance of the observer; **L = 90m**- Closest possible distance between the observer and the furthest player on the pitch,(ap = 0.69°); **BRV=190m** - Boundary of the field of maximum range of view of soccer pitch, angular height of a player αp = 0,54°; **BRVrec=150m** - Boundary of the field of recommended range of view (αp = 0,69°)*

4 The Readability of Informational Signs and Symbols

One of issues tightly associated with a range of visibility in the interior of a mod-ern stadium is a system of the identification of players. It is based on use of signs of numbers, placed on their sports clothing (Fig.7). The fundamental parameter which allows the identification of individual players, considering the distance between an observer and the playing field, is readability of the numbers, which each of them have been marked by.

According to Rules of the International Federation of Football Associations (FIFA), since the year 2005 dimensions of basic number have been increased. Currently its height should be in the range 25-35cm [5]. From the point of view of the requirements of ergonomics the readability of informational graphic characters requires that the angular size of their outer contour should achieve a minimum value equal 0°5' [6], [7]. According to the calculations for a distance specified by the limits of maximum range of vision (190m), the minimum character height should be not less than 28cm.

Limit values for viewing angles are reliable only with ideal conditions. When they do not guaranty proper lighting and transparency of the air the increase of the character size of 1.5 to 2 times is required. It should be emphasized however, that in the ergonomically practice to provide the reliable readability of letters and numbers the optimal viewing angle ψ=0°18' ought to be applied. As seen it is more than three times larger than the minimum angle (ψ=0°5') [8].

Similar results as those obtained by using the above-mentioned optimal viewing angle can be achieved using the algorithm H=L/200, where H is the height of the letters and L is the distance of the observer [9]. This confirms the reliability of both methods and at the same time proves that the reliance on a minimum angle does not provide a readability graphic characters.

Fig. 7. Spatial relationships between the vast pitch and the spectators' zone in the interior of a typical contemporary soccer stadium. The image was taken from the highest row of the stand. Viewers are separated from the arena by a safety net, which impairs the vision quality; (photo: author).

These facts lead to the conclusion, that accepted by FIFA values meet only the minimal anatomical conditions of visual perception and in very limited extent. The practical experience shows that they are not sufficient to ensure full comfort of observation and the readability of informational signs and symbols.

5 Ancient and Contemporary Amphitheatric Buildings

The differences and similarities between ancient and contemporary amphitheatric buildings have been visualized on Fig.8. The main feature that differentiates these two architectural forms is the size of the arena. The dimensions of the rectangular normative arena of modern football stadium may not be less than 130m x 90m.It houses the pitch with dimensions 105m x 68m, which requires grassy outer bands along the outside lines of the playing field as well as a proper space for maintenance services of the arena. Overall dimensions of this vast field increases even more, when in the addition to a football field, it must also accommodate the athletics track.

The arena of Colosseum was much smaller, of an oval shape similar to an ellipse, which the long axis was 76m, and the short one just 47m, wherein the depth of the zone for the 50.000 spectators stretched itself until 54m. Terraces for the audience reflected the elliptical shape of the arena, creating a visibility profile with a slope similar to the profiles of today's stadiums. The elevation of the last row of seats were also similar to those of nowadays. All mentioned parameters caused that the visibility of objects in the arena, but also the visual and acoustic contact of the viewers with an audience situated on opposing site of field of the arena were far superior in quality than those achieved in the interiors of our stadiums.

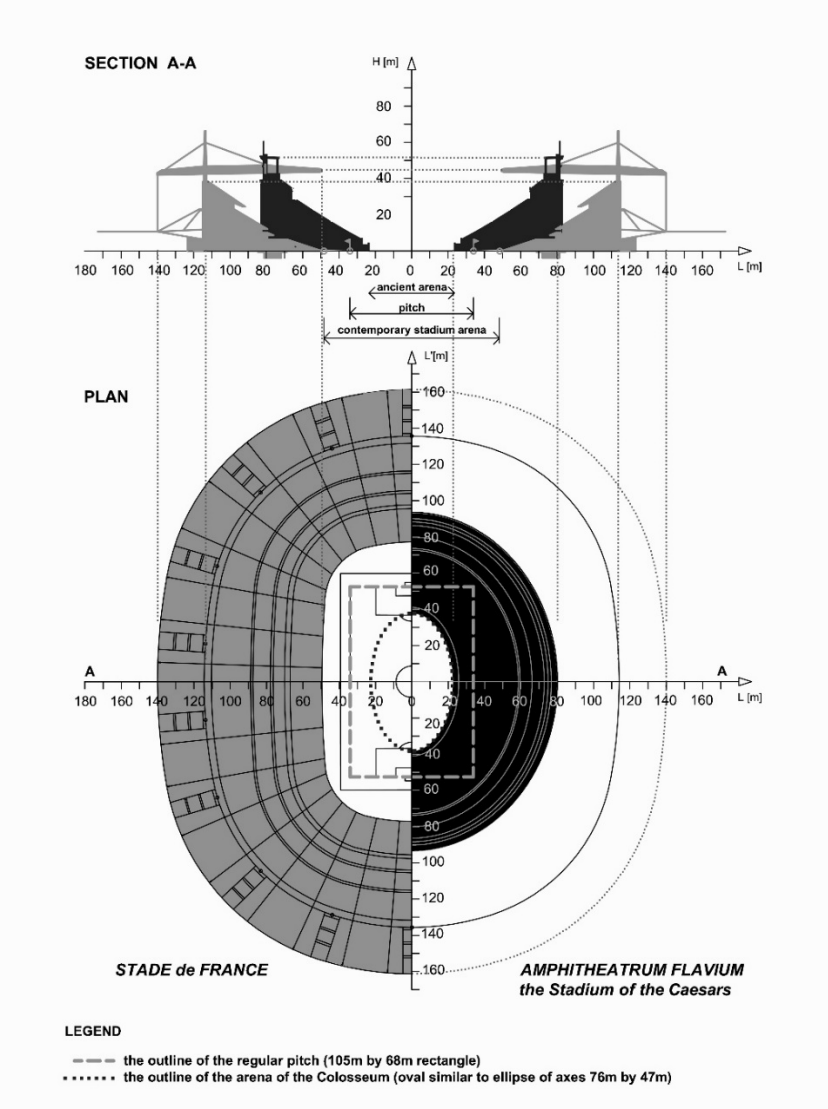

Fig. 8. The comparative analysis of shape and size of the arenas and the spectator zones of ancient Colosseum and contemporary stadium (Stade de France); (author)

In summary, it is clear that the ancient Romans through centuries of practical experiences in the construction of the objects of this type were able to define the most appropriate relationship between shape and size of the arena and space for the audience. With this knowledge, on the one hand, the best visibility conditions, and on the other hand, the biggest capacity of viewers zone, have been achieved. Equally can

be firmly conclude that the poor quality of vision at modern stadiums is a direct consequence of the decisions fixing the huge size of a football field - decisions undertaken long time ago without including an anatomic limits of the human eye.

6 Conclusions

The research on factors determining the development of architectural form of modern stadiums leads to conclusion that the size and shape of the field of game, which is the field of observation, is derivative of the game rules, with no any regard to the factors defining visual comfort of spectators. These game rules, having been in-vented over one hundred years ago, did not take account the fact, that the action on the pitch has, in fact, character of great spectacle, nor the need of coexistence be-tween arena and huge spectator stands. The creators of the rules of the game did not have any knowledge of the army of fans who soon became an inseparable and key part of the football phenomenon.

Fig. 9. The scenes at the 1923 FA Cup final between Bolton and West Ham at newly built Wembley Stadium. The official attendance is 126,047, but some estimates suggest 300,000 showed up for the first ever football match at the stadium. [File from the Wikimedia Commons. Public Domain, http://en.wikipedia.org/wiki/File:Whitehorsefinal.jpg; admittance: 26.01.2014]

Already in the early stages of the football stadium development, it became obvious, that as important as field and rules of the game are needs of numerous observers of the action ongoing on the arena (Fig.9.). From that moment until today, the architects have focused attention mainly on the enlargement and quality improvement of the spectator's zone - but adjusting it in the same time to the constant size and shape of the enormous playing field, defined by the rules of game in half of 19th century.

Soon they realized however, that increasing the capacity of the stadium stands has strict limitations, caused by the anatomical range of vision of human eye.

For the human eye the critical angle of seeing of two points as separate objects equals 0°1' (0,017°). European Standard EN 13200-1 specifies two values of maximum range of sight for soccer stadiums: 190m, as a maximum value and 150m, as recommended one. In case of the first, angular height of the retinal image of soccer ball is ψ=0º4' (0,067°), what means only four time more than critical minimal angle of view. This parameter determines the spatial size of the spectator's zone, its capacity and shape. This in turn translates into qualities of usability, communication and evacuation routes, as well as the construction cost of stadium stands and canopies.

The lengths of sight lines of the furthest objects situated at the pitch are different for each place of the spectator zone and are in the range from 90m to 190m. From such a distances are seen the ball and the players, located in the farthest corner of the playing field. The angular heights of players figures seen on the pitch in critical points of field of vision (pitch corners), for all the viewers, regardless of the place occupied, are in the range of very low values, such as 0,54° - 1,15°. This is due directly to the dimensions of the playing field, defining, in fact, the vast field of observation, which considerably exceeds the capabilities of the human eye in range of full and qualitatively satisfying visual perception.

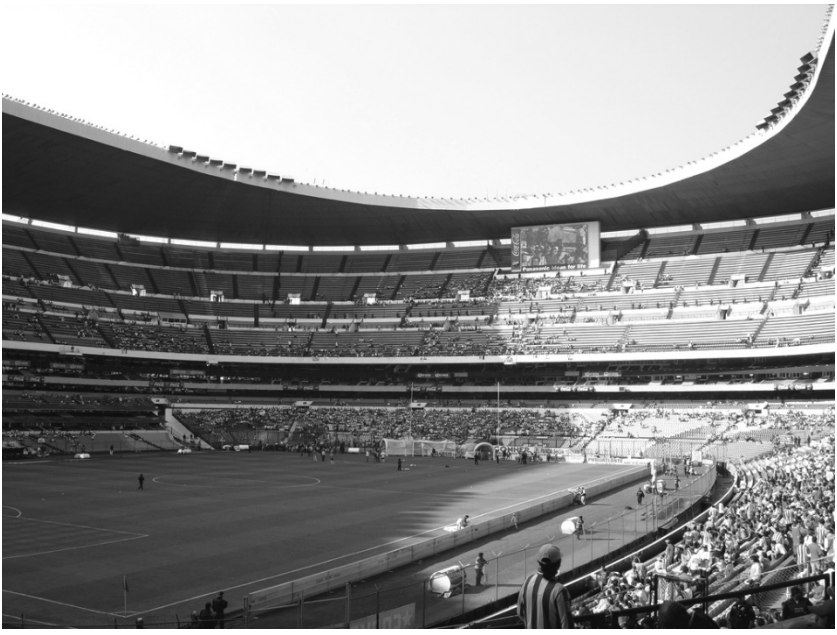

Fig. 10. Interior of The Azteca Stadium (Mexico), one of the world's largest contemporary football stadiums (115.000 seats). Its construction and opening in 1966 marked the beginning of a new architectural generation of football venues. [Author: Jymlii Manzo, Wikimedia Commons, Creative Commons Attribution 2.0 Generic license, http://commons.wikimedia.org/wiki/File:Estadio_Azteca_07a.jpg, admittance: 26.01.2014]

Ancient Romans were those who had knowledge of how to define the most appropriate relationship between shape and size of the arena and proper space for the audience. With this knowledge they were easily achieving, on the one hand, the best visibility conditions, and on the other hand, the biggest capacity of viewers zone. Analysis of these ancient achievements authorizes firmly to the conclusion that the poor quality of vision at modern stadiums is a direct consequence of the decisions fixing the huge size of a football field - decisions undertaken long time ago without including an anatomic limits of the human eye.

All mentioned above facts lead to the conclusion that accepted by football au-thority's values of parameters associated with visibility meet only the minimal ana-tomical conditions of visual perception and in very limited extent. The practical expe-rience shows that they are not sufficient to ensure full comfort of observation of the moving objects and the readability of informational signs and symbols (Fig.10.).

The results of the presented studies evoke many reflection of the architectural nature and among them main guidelines for the future development of stadiums. According to the author the interiors of future stadiums should be shaped considering correct relationships between the needs of spectators and arena. The appropriate standards of the visibility, adjusted to anatomical features of human eye perception, should have the supreme priority in these relationships, consequently causing, as an out-come of these corrected standards, changes in the shape and size of the arena.

References

1. Lapaczewska, K.: Pole widzenia. Badania modelowe. Prace i Materialy, Zeszyt 102, 7–16 (1986)
2. EN 13200-1: The European Standard which has the status of a Polish Standard (2003), PN EN 13200-1: Spectator facilities - Part 1: Layout criteria for spectator viewing area – Specification (2005)
3. John, G., Sheard, R.: Stadia. A Design and Development Guide, 105–120 (1997)
4. Pelczarski, Z.: Widownie współczesnych stadionów. Determinanty i Problemy Projektowe 90, 152–154 (2009)
5. FIFA: Equipment Regulations. Regulations Governing the Sports Equipment at FIFA Competitions, Zurich, p. 13 (2005)
6. Neufert, E.: Podrecznik Projektowania architektoniczno-budowlanego. Ed. III, pp. 37–38. Arkady, Warszawa (2005)
7. Nixdorf, S.: Stadium ATLAS. Technical Recommendations for Grandstands in Modern Stadiums, pp. 130–137. Ernst & Sohn, Berlin (2008)
8. Ziobro, E.: Ergonomia, wybrane zagadnienia, pp. 144–145. Politechnika Wrocławska, Wroclaw (1989)
9. Rosner, J.: Ergonomia, pp. 164–170. Panstwowe Wydawnictwo Ekonomiczne, Warszawa (1985)