Application of Computer Aided Design in Designing Auditorium
Assessment of the Viewing Conditions in Auditoria

Ahmed M. Shehata & Eslam Hamed Al-Ghonemi *

Department of Architecture, College of Engineering, Al-Mansura University, Egypt
* Department of Architecture, College of Fine Arts, Alexandria University, Egypt

Abstract :

Auditorium design is one of the most complicated architectural tasks. Team of specialists is needed to participate in the process. Acoustical designer, lighting designer and air-conditioning consultant in addition to the architect should be among this team.

Within this paper, auditorium basic formats, seating arrangement, audience to stage relationship as design factors were studied in detail. Then the auditoriums' design parameters were discussed illustrating the auditorium Basic Formats, seating arrangement ended by audience to stage relationship. Therefore, the evaluation criteria of auditorium's design were followed, which include visual quality and sightlines and main visual measures. The study include by the evaluating design parameters impact on visual Quality, which discussed the evaluating auditorium form impact, evaluating stage format impact and the evaluating Seating Arrangement effect. Then the paper ended by giving a conclusion of the study.

Therefore, we can say that this paper was dedicated to help designers with the conceptual auditoriums' design. Factors affecting design were discussed. Performance criteria related to the visual conditions were investigated and the impact of the design factors on the performance is evaluated using a computer program that is specially designed to evaluate these aspects. This program works from within the AutoCAD as a drafting environment. It helps with evaluating design decision within the conceptual stage. Several cases were tested using the computer program. The resulted evaluation data were introduced in a set of tables. These data were represented in a group of design charts or could be defined as a design fingerprints.

Introduction :

Through this paper, the issue of auditorium design is studied; the following design factors are introduced in detail:

1) Auditorium basic formats.
2) Seating arrangement.
3) Audience to stage relationship.

Design quality is discussed as well. Several evaluation aspects were introduced. Evaluation criteria aspects concerning the visual conditions were introduced in detail. The direct impact of each of the previously mentioned design factors on each evaluation aspect of these performance criteria was investigated.

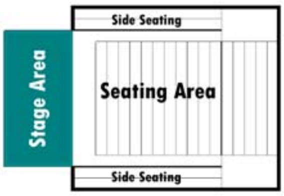
A computer program, specially designed to evaluate certain performance aspects, was applyed in this process. This program works from within the AutoCAD as a drafting environment. It helps with evaluating design decision within the conceptual stage.
Several cases were tested using the computer program. The resulted evaluation data were introduced in a set of tables and in a group of design charts.

Auditoriums' Design Parameters
Designer has to weight many issues related to the interior design of auditoria as room geometry, stage design, human anthropometric variation and seating design and layout. Many parameters affect the designer choice and decision. The following sections discuss three of the main affecting parameters and how they related to each other:

Auditorium Basic Formats and definitions
As defined by the Arts British Council (1996), the following are the most common formats for theatrical performances:
- End Stage: As shown in Figure 1-a, it is a rectangular shape with acting area in one of the rectangle sides with all the seats facing the stage area.
- Courtyard theatre: As illustrated in Figure 1-b, it is a rectangular plan as well as the end stage but with additional galleries along the sides and back of the seating area. This format gives a deeper sense of enclosure.
- Horseshoe shape: Figure 1-c, shows that the basic plan shapes is rounded. This layout gives the same sense of enclosure as the courtyard but the side galleries are rounded. The side galleries in this format have a better viewing angle to the stage than the side galleries of the courtyard format.
- Fan shape: The fan shape could have range of angles between 90° and 180°. As shown in figure 1-d, this format has some characteristics of the end stage. As the angle increase, the stage extends into the audience and it takes on some of the characteristics of the theatre in the round seating area as in the case of horseshoe.
- Theatre in the arena: As illustrated in figure 1-e, the seating in this format surround the central stage. This format could be applied on circular plan or rectangular one. This arrangement suits a particular style of performance.

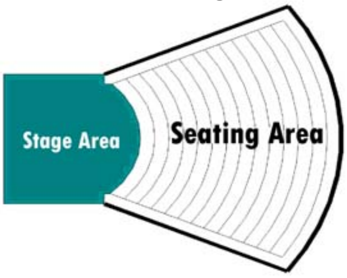
(Strong , 1996; Roderick, 1987).

a. End stage.

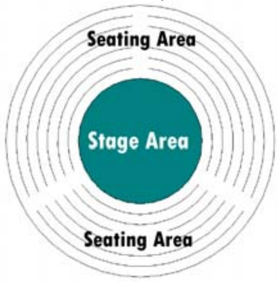


b. Courtyard.

c. Horseshoe



d. Fan shape



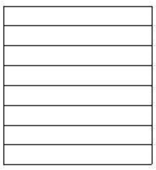
e. Arena

Figure 1. Auditorium basic formats.

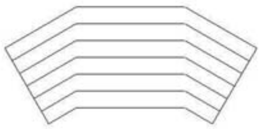
Seating Arrangement :

Comfort and circulation of the audience to and from each seat is the main concern here. For comfort, wide spacing for rows is desirable, but this may reduce the capacity of the auditorium to an uneconomic extent or push the rear rows beyond the acceptable distance from the stage. Dimensions of the seats and aisles as well as their geometry are the main factors affecting the design quality. The following sub-factors related to seating area design:

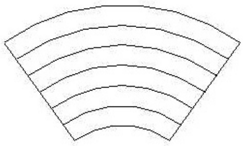
- Rows geometry: Auditorium seating geometry in plan is virtually infinite in variation and combinations. The four basic arithmetical, shown in Figure 2 are applied to many forms of theatre auditor by designers.(Izenohr, 1992).



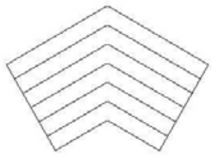
a. Rectilinear



b. Double herringbone



c. Curvilinear



d. Single herringbone

Figure 2. Basic seating formats.

- Rows format: Seats could be arranged conventionally in stepped rows or they could be offset or staggered by a distance equal to half the seat spacing as shown in Figure 3. Spectator clocks between the heads of spectators in the next row and over the head of spectators in the rows after.

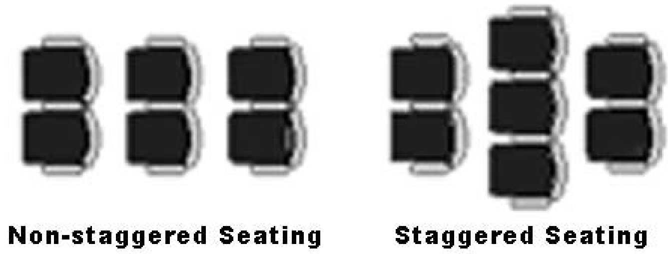


Figure 3. Arrangement of seats in staggered and conventional rows

- Chair types and Dimension: Investigating the alternative seating designs without considering the detailed design of the seats is very misleading. It is very important to decide on the individual chair that is to be used before going through the design stages. (Izenohr, 1992).

  Two main types are used namely Self-rising (spring-loaded) type and Push-back type. Figure 4 illustrates the key dimensions of the chair in both plan and section. Table 1 illustrates the minimum dimensions for the two types. These dimensions are based on the Greater London Council recommendations and the British Standards.(British Standard, 1991)

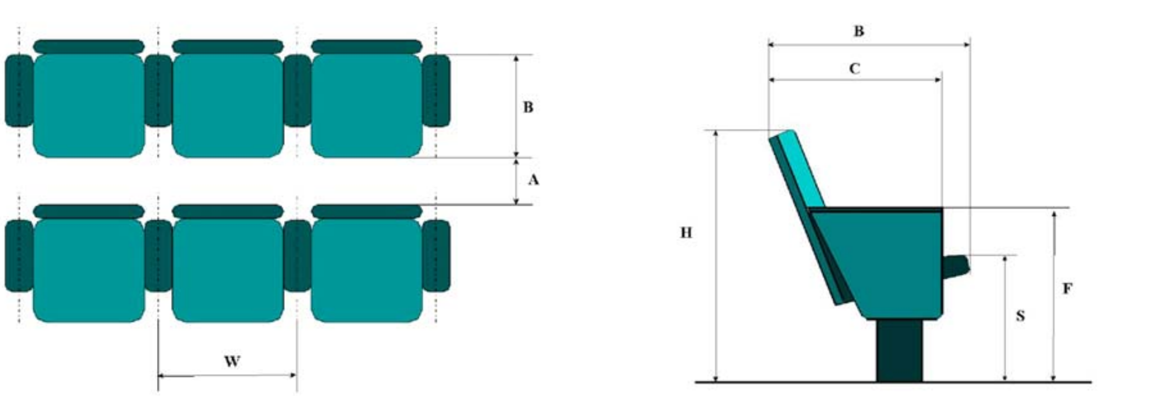


Figure 4. Chair dimensions in plan and section. Izenohr, 1992

Table (1)

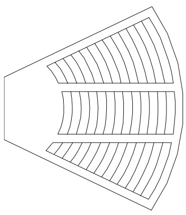
Dimensions of self-rising verses self-rising push-back seats' types

	Self-rising	Self-rising push-back
B	67.5 cm	65.0 cm
C	51.56 cm	39.375 cm
H	81.25 cm	80.825 cm
S	41.875 cm	43.75 cm
F	60.00 cm	59.375 cm
E	97.5 cm	90.00 cm

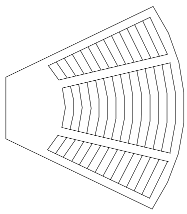
Source: British Standard, 1991

It is important to mention that the self-rising seat is now a standard practice in Europe and it will be considered in this research.

- Types of aisles: Aisles are of questionable desirability except in the largest halls. Many bad sight-lines have resulted from putting the maximum legal number of seats, usually 14 into each row in every section.
- Seating formats: Two main type of seating arrangements are known, the traditional type and the continental type. The term 'continental' seating is generally used to describe seating where each row extends virtually the fully width of the auditorium without any intercepting gangways, i.e. rows in which there are more than twenty-two seats. The conventional seating has two aisle sub-systems. Figure 5 shows both of these subsystems.(Shehata, 1988; Mills, 1979)



a. Parallel asiles

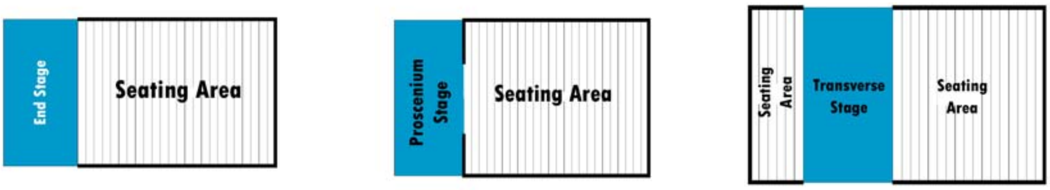


b. Radial aisles

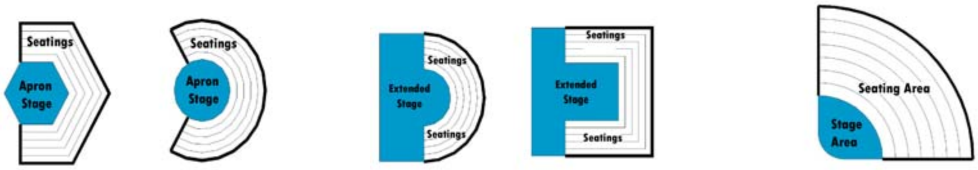
Figure 5. Conventional aisles' sub-systems.

Audience to stage relationship :

Principally, the relationship between the actor and his audience is the basis of “theatre. So, the auditorium to stage relationship is one of the most important matters to be considered”. (Christos 1983). The various forms, which have developed over the last decades, can be defined by the extent of the encirclement achieved. Figure 6 illustrates the basic stage formats: (Mils 1979; Roderick 1987).



a. End stage.   b. Proscenium stage.   c. Transverse stage.



d. Apron stage.   e. Thrust or extended stage   f. 90°Fan stage

g. Arena stage   h. Surrounded stage

Figure 6. Common audience to stage relationship

Evaluation Criteria of Auditorium’s Design :

The physical interior quality needs to be evaluated from several points of view. While the following points define the possible evaluation, aspects the scope of this study will be limited to the visual conditions

- Acoustics.
- Ventilation & thermal efficiency.
- Visual conditions
- Circulation and evacuation

Visual Quality and Sight lines:

The quality of the interface between any performance and the viewer is a function of the type of that performance and the interior space it is housed in. This interior should respond to certain fundamental human capabilities and constraints.

Head movement range: One of the most important architectural factors to be considered is the Bio-mechanical of the human body and the geometry of the visual field. Figure 10 illustrates the horizontal head movement range.

Visual angles: It is the part of the space, measured in angular magnitude, that can be seen when the head and the eye are still. Figure 7, 8, illustrates the horizontal visual range and the eye movement range. Figure 9 illustrates the vertical visual field. (Neufert 1985; Shehata, 1988)

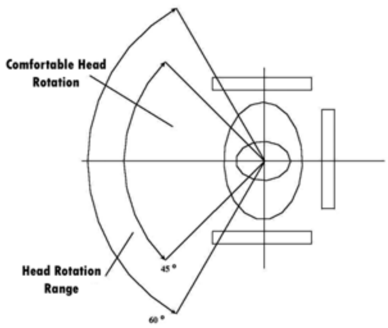


Fig.7. Range of horizontal head movement

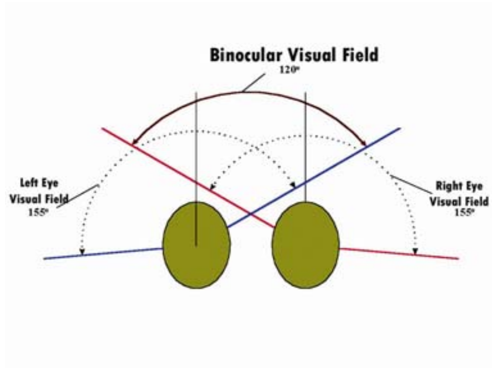


Fig. 8. Range of horizontal viewing range

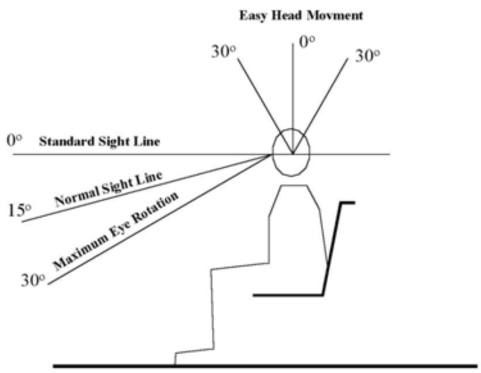


Fig. 9. Vertical head and eye range.

Sight lines clearance: Traditionally, seating rack is deigned in section to allow every spectator to see a design focal point. But, this does not mean that every spectator within the hall will have the same clear sightlines. Also, it does not mean that the spectator will have this clear sightlines to all the stage area. Figure 10 illustrates the spectators' sightlines in section.

Visual Limits: In live shows, performers must be seen to satisfy the audience. Maximum distance from the stage should be limited by the eye capability. Theatres planned to house drama performances must have a depth not over 22.5 meter to allow detail of facial expression and small gesture to be seen. Grand opera and dance halls where broad gestures by single individuals are the minimum to be seen must have a depth of 37.5 meter. (Shehata, 1988).

Main Visual Measures:

Several aspects could be used to judge the visual quality of certain seat within any hall. The following factors are the objective ones:

- The percentage of the stage lattice at a given level that can be seen from any given seat allowing for obstruction by other members of the audience and by the structure elements.
- The distance between seat and stage focus - this focus being specified by the user.
- The vertical angle subtended by the stage plane to the spectator's eye.
- The angle of rotation of the line of direct vision from the seat to the focus.(Shehata 1988).

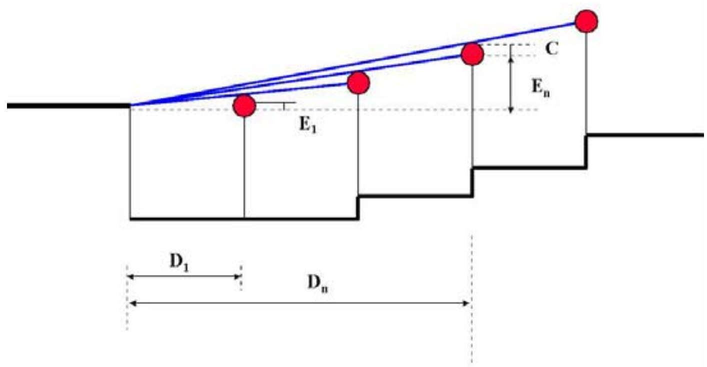


Figure 10. Sightlines in conventional seating.

Evaluating Design Parameters impact on visual Quality:

A full design scheme suggested in Table 2 to investigate the direct impact of the design physical parameters on the auditorium performance. This section investigates the impact of some of these parameters on the audience-space interaction quality. The data of the full population of this scheme, which the study was, depend on, is too large to be included.

Table (2)
A full design schemes for the evaluation aspects verses design parameters:

			Evaluation Aspects							
			Evacuation		Acoustics			Vision		
			Evacuation time	Walking distance	Reverberation time	Sound distribution	Echo	Stage visibility	Viewing angles	Viewing distance
Auditorium basic forms		Rectangle								
		Horseshoe								
		Hexagonal								
		Fan								
		Circular								
Audience to stage relationship		Arena								
		Apron								
		Extended								
		End								
		Proscenium								
Seating Arrangement	Straight	Normal								
		Staggered								
	Curved	Normal								
		Staggered								

A computer program applied on several design solutions. These solutions cover all the changes in the design parameters. The solutions divided into sets of design. Every set designed to test the impact of only one design parameter. Each case of these sets demonstrates one state of this parameter. The evaluation results of this case represent the impact of that parameter on the performance. The parameters represented in this scheme are:

1) Basic plan form: Rectangle, Square, Fan, Hexagonal, Horseshoe, circle.
2) Audience to stage relationship: Proscenium, Apron, Central, Extended, End stage.
3) Seating geometry: straight rows, curved rows and seating format: normal seating, staggered seating.

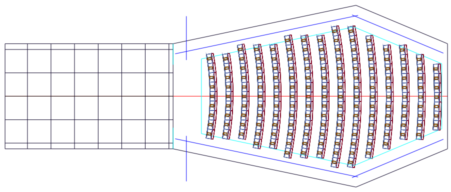
The measured evaluation aspects of performance are:

- The stage area percentage visible to the seated person.
- Horizontal angle subtended between of the seated person's eye to the focal point of the stage.
- Vertical angle between the eye of the seated person and the focal point of the stage.
- Viewing distance between the eye of the seated person and the focal point of the stage.

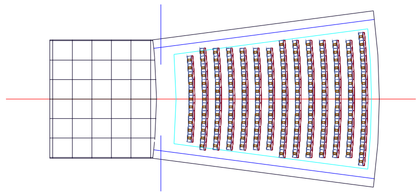
Evaluating Auditorium Form Impact on the Viewing Conditions:

The basic plan formats shown in figure 11 were selected to investigate the form impact on the auditorium performance. Both circular and square shapes were excluded for geometrical reasons. All tested cases have the following design features:

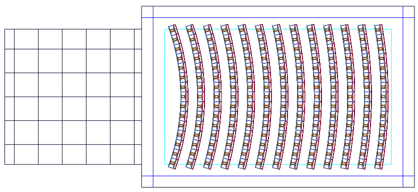
Total seating area:	135 m2
Total stage area:	50 m2
Stage format:	Proscenium stage.
Row's geometry:	Curved rows.
Rows format:	Conventional.
Seating arrangement:	Non Staggered.
Length to width ratios:	1: 1.5



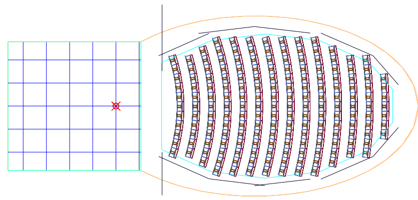
a. HEXAGONAL



b. FAN



c. RECTANGLE



d. HORSESHOE

Figure 11. Selected plan formats to evaluate visual conditions.

Three aspects were investigated to evaluate the visual comfort. Stage visibility to every member of the audience, viewing angles to focal point and viewing distance. It should be noted that All the cases are designed up to the standard. This means that every seat in all the tested cases has clear sight lines to the selected focal point. This focal point lies on the stage surface (1.1 meter from the ground level of the first row) at 1.0 meter back from the stage edge. Table 3 presents the averages and the standard deviations for the evaluated cases.

Table (3)

Average values of visual evaluation data and their corresponding standard deviation for different plan forms:

Location of Audience	Stage visible percent (%)		Vertical viewing angle (Degree)		Horizontal viewing angle (Degree)		Distance from focal point (meter)	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
Rectangle	98.47	2.17	8.98	4.98	6.73	6.10	9.20	3.29
Horseshoe	83.37	6.86	8.32	3.28	8.27	6.03	8.40	3.29
Fan	99.05	1.58	10.86	4.07	9.78	7.55	9.40	3.50
Hexagonal	73.84	13.35	9.48	3.46	4.95	4.03	9.99	3.45

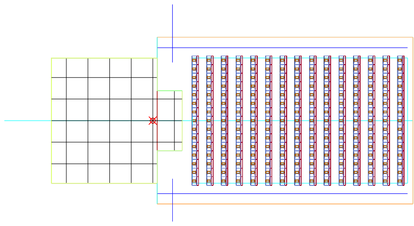
The following points could be concluded from table 3:

- Stage visibility: The horseshoe and the hexagonal shapes give a better average visual percentage. This is because most of their audience populations are concentrated in the middle part of the hall. In the rectangle case, the populations are distributed equally on the hall. In the fan shape most of the audience population lies in the rear rows.
- Vertical viewing angles: There is a very small difference in the average of the vertical angle between the four tested cases. Also the standard deviations for the four cases are very similar. This lead us to conclude that the form does not have any effect on the viewing vertical angle.
- Horizontal viewing angles: There is a small difference between the four cases, The different distances between the first row and the focal point for each case cause this difference. The fan shape has a bigger difference in the angle in each row. This is because of the long rows that created by the fan shape. The hexagonal shape has the best standard deviation. This is because the majority of the audiences are concentrated in the middle of the hall. This creates smaller and more homogeneous viewing angles. The fan shape has the biggest average, which are not as good as the other cases. In addition, it has the biggest standard deviation, which implies that it has the biggest extremes as well.
- Viewing distance: that the difference between the average distances is less than 1.5 meter which is not significant difference. As a result, one can say that the form does not affect viewing distance.

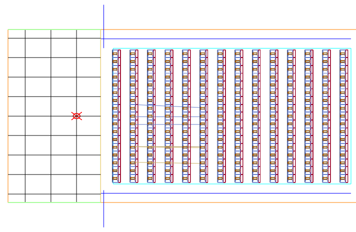
Evaluating Stage Format Impact:

Figure 12 illustrates the selected basic stage formats to investigate the audience to stage relationship effect on the auditorium performance. They all have the same next design features:

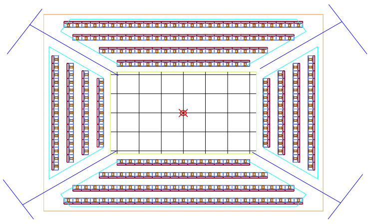
a.	Total seating area:	135 m^2
b.	Total stage area:	50 m^2
c.	Stage format:	Proscenium stage.
d.	Row's geometry:	Straight rows.
e.	Rows format:	Conventional.
f.	Seating arrangement:	Non Staggered.
g.	Length to width ratios:	1: 1.5



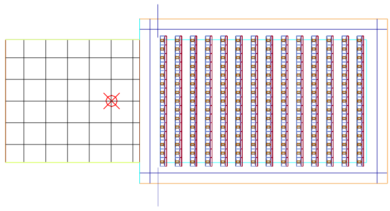
a. Apron.



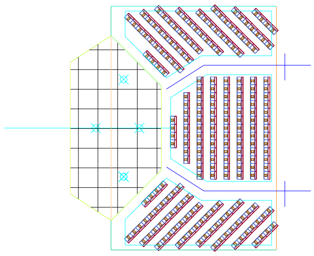
b. End stage.



c. Central Stage.



d. Proscenium.



e. Extended.

Figure 12. The Selected plan forms to test the stage format impact on the auditorium performance.

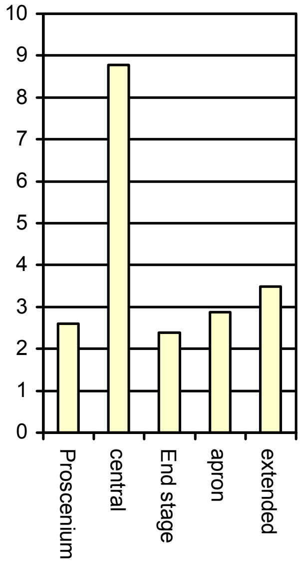
The five cases were tested to investigate the effect of the different audience to stage relationship on the visual conditions. Table 4 and figure 13 present the averages of the evaluation results.

Table (4)
Average values of visual evaluation data and their corresponding standard deviation for different stage formats

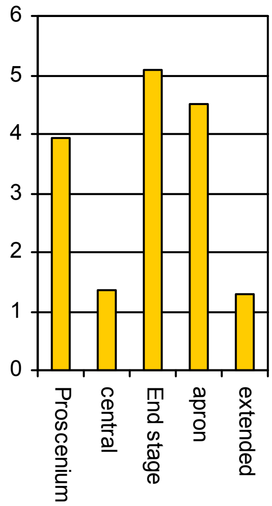
	Stage visible percent		Vertical viewing angle		Horizontal viewing angle		Distance from focal point	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
Proscenium	95.98%	2.60	10.06°	3.94	14.65°	11.13	8.97 m	3.53
central	92.04%	8.78	5.81°	1.37	23.94°	14.87	5.81 m	1.34
End stage	99.30%	2.39	13.25°	5.07	19.49°	15.03	8.08 m	3.04
apron	96.97%	2.87	11.90°	4.52	15.50°	12.28	8.95 m	3.47
extended	93.12%	3.49	8.95°	1.28	10.11°	6.50	8.95 m	1.94

The following points could be concluded from table 3 and figure 12:

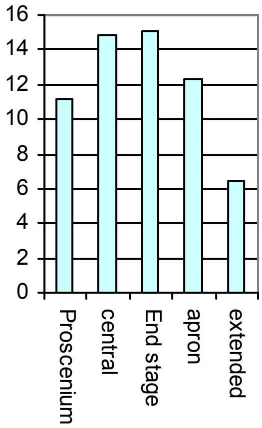
- Stage visibility: Both central stage and extended one have unexpected obstructed sight lines. This happened because of the position of the focal point and its relation to the total area of the stage. The proscenium stage and end stage give the best average visible percentage. The standard deviation for both of them also is very good in comparison to the other cases. From the table and the figure, it is concluded that the stage format has strong impact on the stage visibility to the audience.
- Vertical viewing angles: There is a very small difference in the average of the vertical angle between the extended, apron and end stage. The central stage has the best angles and the best standard deviation. The central stage has the smallest vertical viewing angles and the smallest standard deviation. This is because of the nature of this type of stage format, where most of the audience is very near to the stage. This leads us to conclude that some of the stage formats have a very strong impact on the average vertical viewing angle.
- Horizontal viewing angles: There is big difference in both the averages and the standard deviations. The extended stage has the smallest angle and the best standard deviation while the central stage has the biggest average angle and the biggest standard deviation. It is clear that the stage format has a very strong impact on the viewing angles.



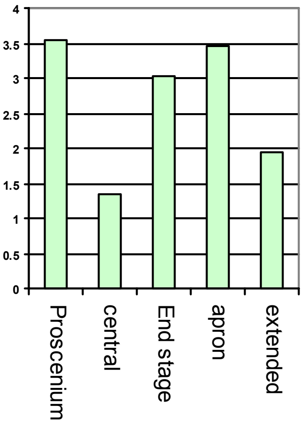
Stage visible percent



Vertical viewing angle



Horizontal viewing angle



Distance from focal point

Figure 13. Visual qualities of different stage formats.

- Viewing distance: The central stage has the smallest average viewing distance and the smallest standard deviation. The four other cases have a very near averages and standard deviation. It could be concluded that some of the audience to stage relationships affect the viewing distance but most of them have no effect.

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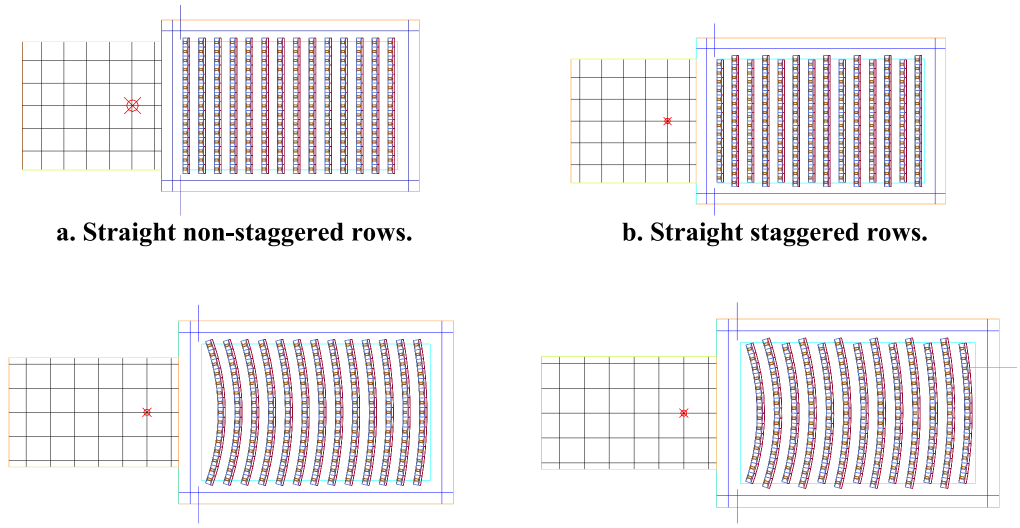

a. Straight non-staggered rows. **b. Straight staggered rows.**

c. Curved non-staggered rows **d. Curved staggered rows**

Figure 14. Plans of selected seating formats and row's geometries.

Evaluating Seating Arrangement effect:

The next case studies present different seating formats and row's geometries for the conventional seating arrangements. They all have the next design features:

Total seating area:	135 m^2
Total stage area:	50 m^2
Stage format:	Proscenium stage.
Rows format:	Conventional.
Length to width ratios:	1: 1.5

The visual conditions for each seat within the previous four cases were tested. Table 5 and figure 15 presents the average of the measured values for the visual evaluation aspects:

Table (5)
Average values of visual evaluation data and their corresponding standard deviation for different seating formats

	Stage visible percent		Vertical viewing angle		Horizontal viewing angle		Distance from focal point	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
1-Straight_Normal	95.95%	2.62	9.99°	3.75	14.81°	11.24	8.83 m	3.45
2-Straight_Staggered	74.93%	12.35	5.56°	1.85	14.30°	10.78	8.71 m	3.36
3-Curved_Normal	84.84%	12.60	8.88°	3.51	6.82°	6.13	9.09 m	3.22
4-Curved_Staggered	80.37%	10.80	4.95°	1.74	6.65°	5.90	8.96 m	3.13

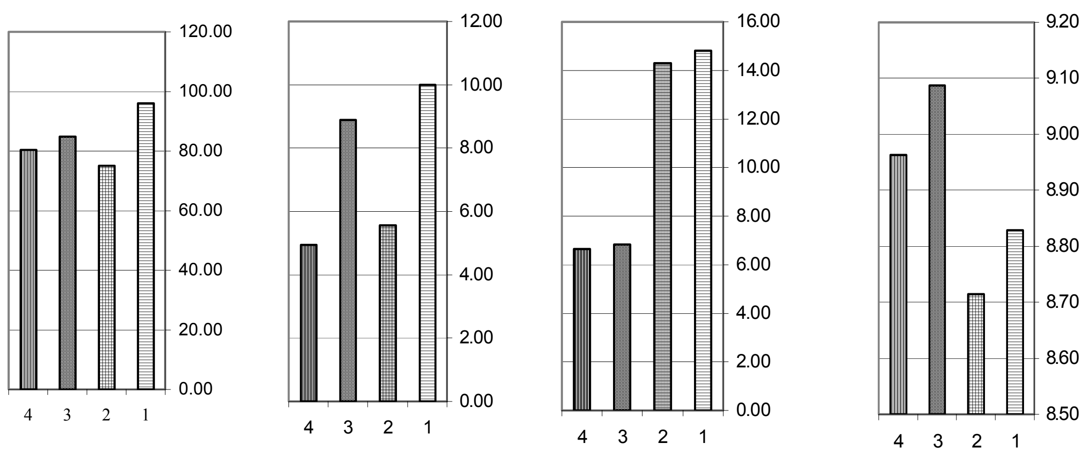

Figure 15. Visual qualities for different seating formats and row's geometries.

Both table 5 and figure 15 shows the following points:

- Stage visibility: There is no significant difference between the curved rows and the straight rows if they have a non staggered seating format. For the staggered seating format, the chart shows that the curved rows improve the average stage visible percentage. It could be concluded that rows' format (staggered or non staggered) has strong impact on the average visible percentage of the stage.
- Vertical viewing angles: There is no difference between the straight and the curved rows. The curves of the non-staggered format are higher than the curves of the staggered formats, which is logic.
- Horizontal viewing angles: There is big difference in the horizontal viewing

angles between the straight and the curved rows. Also it is obvious that the seating format (normal – staggered) does not have effect on the horizontal viewing angles.

- Viewing distance: The straight rows tends to have a longer viewing distance especially at the rear rows. The seating geometry (curved or straight) has a strong impact on the viewing distance. While the seating format (staggered or non-staggered) does not affect the viewing distance.

Conclusion

Table 6 summaries the concluded relationship between design factors and the different visual aspects.

Table (6)
Concluded relation between design factors and evaluation aspects

	Stage Visibility	Horizontal Viewing Angles	Vertical Viewing Angles	Distance from Stage
Auditorium basic plan fromat	●	○	○	●
Rows format. (Staggered – non-staggered)	●		●	
Rows geometry (Straight – curved)	●	●	○	
Audience to stage relationship	●	●	○	●

Strong impact ●
Small effect ○
No effect

The following comments are concluded out of table 6:

- Stage visibility is a very sensitive aspect. Each one of the design factors has strong impact on it.
- The vertical viewing angles are affected by the rows format, the rows geometry and audience to stage relationship.
- The horizontal viewing angles are affected by the stage format and the rows geometry.
- The viewing distance is affected by the basic plan format and the relationship between the seating are and the stage.

- The plan form does not have a direct impact on the vertical viewing angle. It has effect on other physical parameters like number of rows, distance of first row from focal point, etc. These parameters could affect the vertical viewing angles.
- The rows' geometry (curved or straight) has strong impact on the horizontal viewing angles and has a very small impact on the vertical viewing angles.
- The seating format (staggered or non-staggered) has strong impact on the vertical viewing angles and it has no effect on the horizontal viewing angles.
- Audience to stage relationship affects stage visibility. Central stage has the worst average and standard deviation while the end stage gives the best average and standard deviation.
- With the exception of the central stage, audience to stage relationship does not affect the horizontal viewing angles.
- Straight rows give better horizontal viewing angles than the curved rows.
- The non-staggered seating arrangement gives smaller vertical viewing angles this has a flattening effect on the floor dish.
- Curved rows give a better stage visibility than the straight.
- Basic plan format has a great impact on the stage visibility and the viewing distance.

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التصميم بواسطة الحاسب الآلي لقاعات الاستماع

أحمد عبدالرحمن شحات و إسلام حمدي الغنيمي ❖
قسم الهندسة المعمارية – كلية الهندسة – جامعة المنصورة – جمهورية مصر العربية
❖ قسم العمارة - كلية الفنون الجميلة – جامعة الإسكندرية – جمهورية مصر العربية

الملخص:

إن تصميم قاعات الاستماع وصالات المحاضرات العامة تعتبر من أكثر عمليات التصميم المعماري تعقيدا. فنجد فريق عمل مكون من تخصصات مختلفة كثيرة تشارك في عملية التصميم. مصممين متخصصين في الصوتيات والإضاءة وتكييف الهواء فضلا عن المصمم المعماري الذي يجب أن يكون ضمن هذا الفريق.

وخصصت هذه الورقة لمساعدة فريق المصممين لتفهم فكر تصميم قاعات الاستماع بصفة عامة مع مناقشة العوامل المؤثرة على عملية التصميم. وقد تم بحث معايير عناصر التصميم التي تؤثر على معدل الأداء الأمثل لهذه القاعات ودراسة تأثيرها بالإضافة إلي عمل تقييم لهذه العناصر على أداء القاعات.

التأثير المباشر لمظهر وسمة كل من عناصر التصميم على كل من معدلات الأداء تم تقييمه مستعملين برامج الحاسب الآلي المتخصصة والتي تختص بمثل هذه العمليات. ونظرا لتعقيد وكثر تفاصيل الدراسة وطول الفترة الزمنية التي استغرقها الباحثان في عمليات التقييم الذي تم تناولها وتنفيذها أثناء البحث فقد تم تقديم ملخصه واستنتاجاته في صور رسومات بيانية أو أشكال.