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THE BEST REMAINING SEAT:
EVALUATING AUDITORIUM PLANS FOR DESIRABILITY

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1. INTRODUCTION

Looking at the great variety of auditorium plans you may wonder: "Are some plans better than others?"

Numerous design considerations must be balanced in the design of an auditorium. Acoustics, building codes, economic considerations, space efficiency, sightlines and comfort are all important. Historic precedents, tradition and aesthetics must be considered as well. But it is also important that an auditorium be designed to have as many good seats as possible.

We know from experience that all seats in an auditorium are not equally good. This is manifested in that the audience does not choose its seats randomly. The audience understands intuitively that, generally speaking, the closer a seat is and the more straight on, the better it is. Had the seat selection been random, then the chosen seats would have been distributed evenly throughout the auditorium.

Imagine an auditorium with open seating and imagine the audience entering the auditorium one at a time. People will in turn make a selection of what in their opinion is the best remaining seat. The first seats to be selected are the ones somewhere in front and towards the center. When these seats are taken the audience chooses seats further back and off to the side. Where people prefer to sit is an indication of which seats in their opinion are better than others. The order in which the seats are chosen is an indicator of the rank order of the desirability of the individual seats. The audience is performing a post evaluation of the desirability of the seats in the auditorium.

As the audience makes its seat selection, a geometric pattern of the occupied seats unfolds and reveals the boundary around the preferred seats. At any point in time the seats in the perimeter of the occupied seats describe the outline of the most desirable auditorium plan from the audience point of view. The perimeters describe the equal desirability curves. By studying the order in which the seats are selected and the boundary of the selected seats, it is possible to determine which room geometry will result in an auditorium with as many good seats as possible. In the end such data can be translated into useful information that the architect can draw from when planning a new auditorium.

2. PREVIOUS STUDIES.

1/ A pioneering paper on this subject was presented by the acoustician Paul S. Veneklasen at the conference on Auditorium Acoustics, 1975, Edinburgh, Scotland. [3] He briefly discussed this paper at the Wallace Sabine Centennial Symposium, 1994, Cambridge Mass. [9] Veneklasen's study is discussed below.
2/ The subject is also addressed by Harold Burris-Meyer and F. G. Cole in their book "Theatres and Auditoriums". [4] Their study is quoted in "Time-Saver Standards for Building Types" and "Time-Saver Standards", two books widely used as references in architectural offices in the U.S.A.. Burris-Meyer and Cole's guidelines are not explained or justified. Furthermore, they are not dimensioned and the order of

desirability of the seating areas, which is measured from A through F, jumps so that, for example, the area assigned a desirability value of B abuts the area of F. This does not make sense.

3/ Theatre managers have, whether conscious of it or not, made a desirability evaluation of the seating plan. The price categories of the seats in an auditorium reflects such an assessment. A comparison of ticket price structures as they relate to the desirability of the seats is beyond the scope of this paper and not included.

4/ A number of textbooks record and classify auditoria into families, such as for example 'shoe box' and 'fan shaped' auditoria. [2] [6] [7] The work is descriptive and mostly concerns historical developments. Michael Barron [1] provides information that aids our understanding of what effect room dimensions and geometry have on the acoustics of an auditorium. Michael Barron's study is thus similar in scope to the one presented here in that it isolates a design consideration and systematically comes to grips with its implication for auditorium design.

3. DATA GATHERING AND RECORDING.

The desirability of a seat is defined as how popular a seat is. This can be deduced by studying which seats are taken before others as well as from studying the frequency with which a seat is chosen in auditoria with open seating. It turns out that these two measures result in virtually the same outcome.

The audience choice of seat is recorded by time lapse photography. As soon as the audience enters the auditorium the first picture is taken. Additional pictures are then taken at regular intervals thereafter. Data are gathered in the same auditorium a number of different times in order to verify the consistency of the preferred seats. Different auditoria are studied in order to study seating preferences in auditoria with different room geometries. The photographic data were transferred into computer data. It is from these data that the mathematical model is developed and analyzed in a combined computer drawing and mathematics program. (DesignCAD).

In order to hold as many unknowns constant the study was done with the following constraints:

1/ Only auditoria with open seating were studied.
2/ Only auditoria for concert use were studied.
3/ Only the floor of the auditoria were studied
4/ Only shoe box auditoria were considered.

4. THE EMPIRICAL STUDY

Two auditoria have been selected to illustrate the data and the derivation of the mathematical model.

1/ Odense Koncerthus, Carl Nielsen Salen, Odense, Denmark.
2/ Arkadenhof des Wienerrathauses, Vienna, Austria.

These two auditoria differ in some ways and are similar in others. They differ by the number of seats (Odense 1198 seats, Vienna 2960 seats). They also differ in area allocated per seat (Odense 62cm * 95cm, Vienna 40cm * 90cm) and by the orchestra platform dimensions (Odense 20m * 10.25m, Vienna 14m * 12m). The two auditoria have the same width of 32m, but differ in depth (measured from the orchestra platform: Odense 35m, Vienna 64m). Odense is an enclosed space and Vienna is in the open air enclosed on all sides by the Vienna City Hall. Both auditoria have a "conventional" seating arrangement. The first illustration shows a typical computer data plot. It shows Odense Koncerthus at four different concerts.

Care is taken to compare data sets of equal size. The data sets illustrated have 268, 266, 256 and 364 data points respectively.

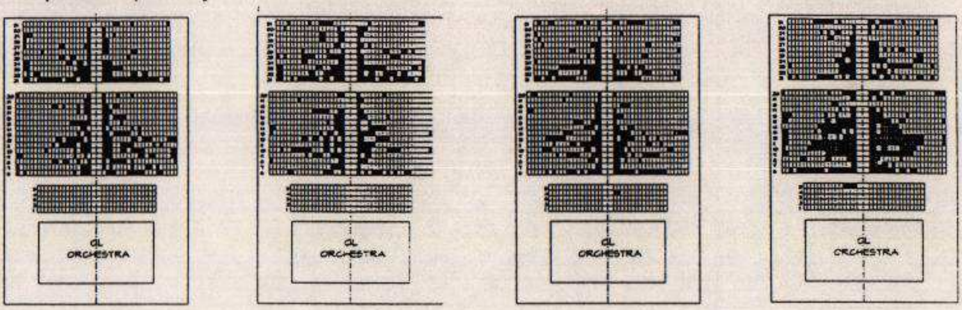


fig. 1 Odense, true plot, four data files

The data shows that one side of the auditorium is not preferred to the other, in that both sides have approximately the same number of data points. Therefore we can obtain a better picture by plotting the data from the right side on top of the left, and mirror imaging the double plot. Furthermore, some noise in the data is inevitable. Clearly the first and last row of seats are very popular, as are the aisle seats. These type of seats are chosen because it is desirable to be seated at the edge of a bank of seats, and not because of the seat location in its relation to the orchestra platform. The data can therefore be cleaned up by ignoring these data points. The same data sets are again used to illustrate removing this noise from the data. It is amazing how similar the data plots are to one an other. Virtually the same geometry develops from one time to the next.

It is important to note that the way you enter the auditorium in Odense Koncerthus traps you in the upper level or lower level. It is possible to move from one level to the other, but it is very inconvenient. Therefore the data in the two parts of the auditorium will be considered independently.

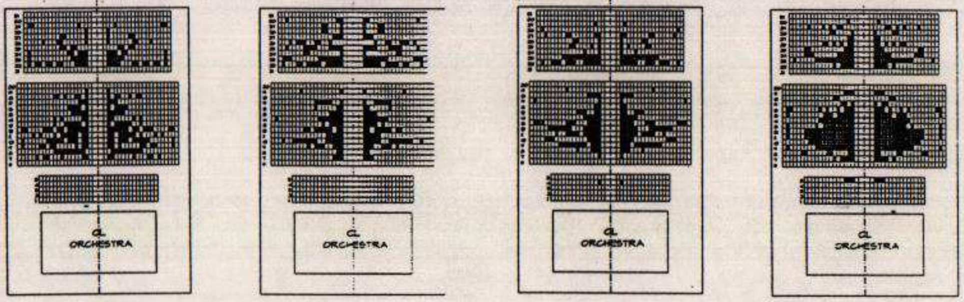


fig. 2 Odense, plot mirror image minus noise.

Looking at the sequence of observations of one data file alone, it is possible to observe how the geometry of the occupied seats unfolds. As the number of seats occupied increases, so does the density within the populated area. Presented below are four data plots from one concert. The time lapse photographs were taken at a time when the number of seats occupied were 68, 165, 268 and 422. Noise has been removed.

In the end where the auditorium is almost filled to its capacity the data plot becomes uninteresting because the geometry of the occupied seats are lost, and you are left with the outline of the seating banks. It is only in the earlier runs where the density is low that you can detect the geometry of the preferred seating area.

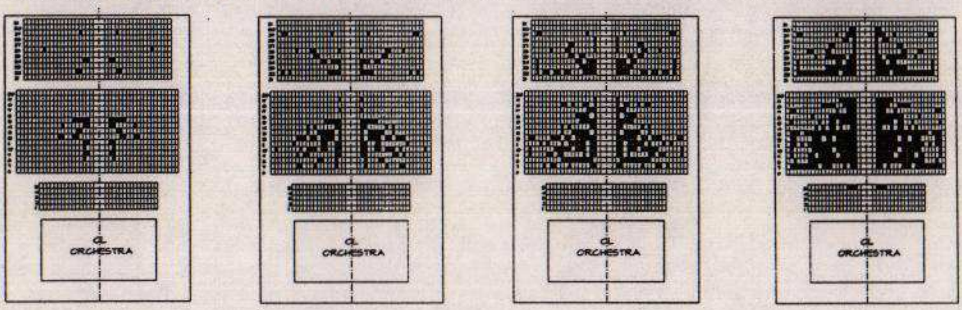


fig. 3 Odense, time lapse observations of one data file.

The next step is to plot different data sets on top of one an other. Illustrated below are 3 data files superimposed. The result is 6 superimposed data sets. We are now able to study which seats are more popular than others. The drawings illustrate which seats are chosen 6 times, which seats are chosen 5 times or more, which seats 4 times or more and 3 times or more. It is interesting to note that the geometry of the order of seat selection greatly resembles the geometry of the popularity of the seats.

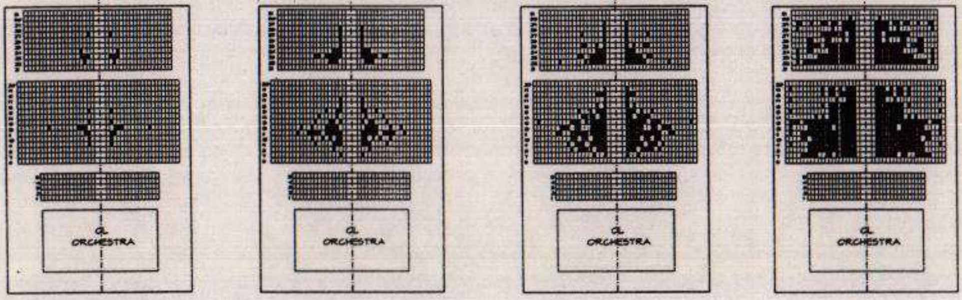


fig. 4 Odense, three data files plotted on top of one an other.

Turning now to Vienna one data file is plotted below showing the order of seat selection. Although you can detect generally a similar geometry outlining the preferred seats as in Odense, the center, the location of the most desirable seat, is located closer to the orchestra platform and the geometry is narrower and more elongated.

Comparing the two auditoria by looking at their data plots it appears as though the width of the orchestra platform creates an imaginary boundary and is a determining factor as to how far off to the side the audience prefers to sit. It appears as though the optimal distance of the preferred seats to the center of the orchestra platform is related to a line of 30 degrees off the center line and intersecting with the imaginary boundary defined by the width of the orchestra platform. The center of the orchestra platform has been chosen as a measuring point also because it can be located with great accuracy.

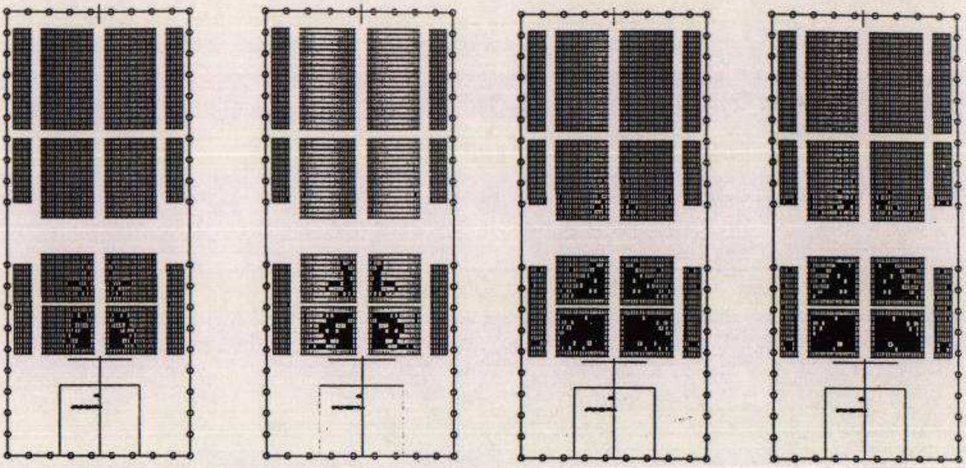


fig. 5 Vienna, time lapse observations of one data file.

5. DEVELOPING THE EQUATION: Trade off between distance and angle.

There exists a seat in an auditorium that has the highest desirability. This seat is located on the center line and at the optimal distance from the measuring point on the orchestra platform. Moving away from this seat location in any direction yield seats that are less desirable.

The optimum seat is defined as having a value of one. It has a distance, an optimal distance, to the measuring point on the orchestra platform, L_{opt}. The desirability of the seats as you move away from this point declines linearly. Seats located at a distance of more than 60m from the measuring point will be defined as having a value of 0. This distance is noted as L_{max} meaning the maximum acceptable distance. The maximum acceptable distance is not an arbitrary number, but builds on work by others [5]. After many trials and errors the following equation was chosen because its resulting geometry reasonably resembles that of the empirical data. The desirability is measured from one to zero, one being the seat with the highest desirability value, and zero the one with the least. Seats with a desirability value less than zero are assigned a value of zero. The desirability value is an ordinal measure and not a cardinal measure. The resulting values are relative and not absolute. Further research is planned to study ordinal/cardinal utilities.

i = the angle off the center line measured from the measuring point.
L = the distance of the seat in question measured from the measuring point.
w = the width of the orchestra platform.
L_{opt} = optimal distance or $(w/2)/\sin(30) = w$.
L_{max} = maximum acceptable distance or 60m.

$v = \cos^2(i)-((L-L_{opt})/(L_{max}-L_{opt}))$, the desirability value of a seat location. For $v<0 \Rightarrow v=0$

$V = \sum v$, the overall desirability value of the auditorium.

The first part of the equation indicates that as the seat location moves away from the center line, the desirability falls off by the square of the cosine to the angle. The subtractive part of the equation describes the percentage the seat is located away from the optimal distance. The computer drawings below show the curve fitting using the above equation in the two auditoria.

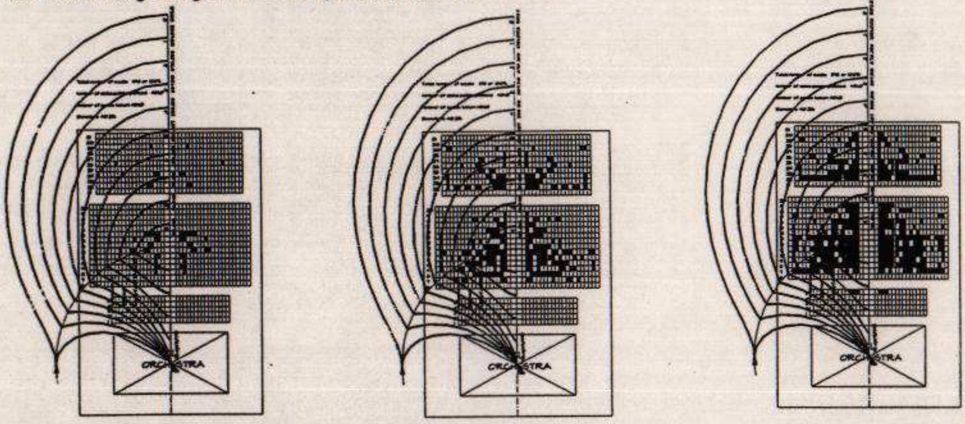


fig. 6 Odense, the mathematical model, curve fitting.

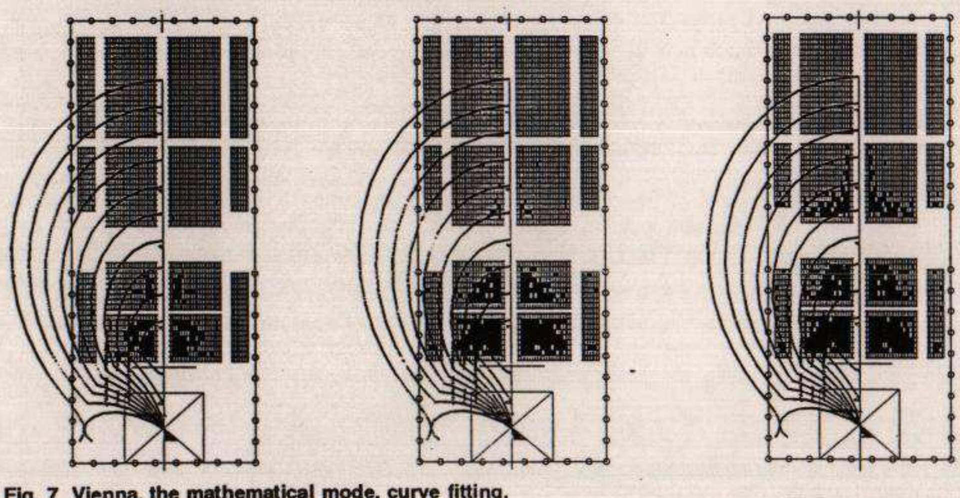


Fig. 7 Vienna, the mathematical mode, curve fitting.

Density calculations are shown in the fig. 8. As the auditorium fills the density within the desirability contours of .9 and .8 are calculated and plotted. This information is compared to the density outside the contour lines and to the density of the auditorium as a whole. If seat preference were random, then these three measures would have been identical. They are not. The percentage of occupied seats within the desirability curves are substantially higher than the percentage of occupied seats outside the same contour lines.

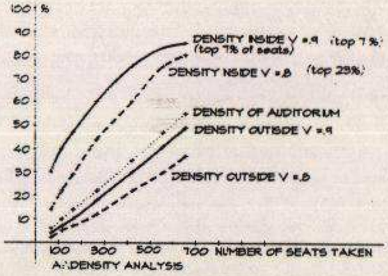


Fig. 8 Density calculations

6. VENEKLASEN'S STUDY. [3]

Veneklasen calls the desirability value the "effectiveness factor". His effectiveness factor is a product of five functions: distance, horizontal angle, floor slope, under balcony isolation and elevation angle. The values are presented in form of graphs. The equations corresponding to the graphs are not shown, nor are the equal effectiveness contour lines. The three last factors evaluate parameters of the seating that are secondary refinements and go beyond the seat location. These factors are also important in an evaluation, but can be considered independently. Other examples of refinements are, for example, seat size and seat staggering, factors also not considered in this study.

By holding the last three factors of Veneklasen's study constant, only considering values relating to distance and horizontal angle, it is possible to plot his equal effectiveness contours and compare them with the equal desirability contours developed in this study. Figure 9 summarizes Veneklasen's study showing his effectiveness contour lines. The effectiveness contour lines are superimposed on a typical data file of this empirical study. The contours do not resemble the outline of seating preferences of the empirical data collected in this study. However, the study presented here certainly builds upon Veneklasen's pioneering efforts.

fig. 9 Veneklasen's equal effectiveness contours.

7. MACRO-ANALYSIS, the potential desirability of the auditorium plan.

An auditorium plan has a potential desirability value inherent in its room geometry. Imagine an auditorium plan divided into unit areas. This is an auditorium with no aisles and no wasted space. How the seats eventually are arranged within this space can be done in many ways and is discussed in the 'Micro-Analysis' below. The higher the overall potential desirability value, the better are the chances for designing a seating plan within that space with as high a desirability value as possible. The unit area can be measured in m^2, or it can be divided into units corresponding to the area allocated per seat. Each unit area is associated with a desirability value. The potential overall desirability of an auditorium plan can be calculated as the sum of the desirability values of the unit areas: $V(1) = \Sigma v$.

This definition implies that the desirability of an auditorium plan always can be improved by increasing the number of unit areas. Therefore, alternately, the potential desirability value of an auditorium plan can be related to the average desirability value per unit area: $V(2) = \Sigma v / A$, where A is the number of unit areas.

Changing the geometry of the auditorium plan will cause a change in the potential desirability value. The geometry that produces the maximum potential desirability is an auditorium plan which follows the geometry of the equal desirability curves. For a number of reasons this geometry is rarely suitable. The geometry is shown in fig. 10 with an area shaded equal to that of Odense Koncerthus. The potential desirability value $V(2) = 0.6224$.

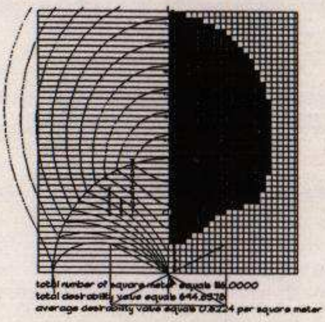


fig. 10. Geometry of the auditorium plan with the highest potential desirability value.

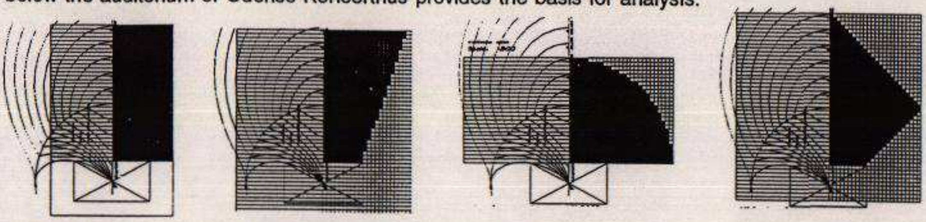
An auditorium of a certain area could be long and narrow, square, or it could be shallow and wide. We are able to calculate which shoe box geometry yields the highest potential desirability value. As an example a shoe box auditorium with an area equal to the one of Odense Koncerthus has been evaluated. The evaluation shows that the winner is: 31m wide and 36m deep with a corresponding potential desirability value of $V(2) = 0.5993$. The dimensions are remarkably close to the ones of the Koncerthus. (32m wide, 35m deep, $V(2)$=0.5975).

Fig. 11 below to the left shows the potential desirability value as it changes with room geometry with an area equal to Odense.. The curve is rather flat, which indicates that within a range the width to depth relationship is not very sensitive. To the right is a graph showing the optimal proportional relationship of width to depth (w:d) for different size auditoria calculated with a 20m wide orchestra platform. For small auditoria the w:d relationship is approximately 1:1.5. As the area of the auditorium increases this relationship changes to 1:1.

fig. 11 Optimal relationships of width to depth of the auditorium plan.

8. ANALYSIS OF HISTORIC EXAMPLES.

Using the method of the macro-analysis described above we are now able to compare auditoria of different geometries for their desirability. This is assuming that the equation holds for other basic geometries as well. Instead of analysing actual examples of auditorium plans, it is more meaningful to consider auditoria geometries, holding the area of the auditorium and size of the orchestra platform constant. In the example below the auditorium of Odense Koncerthus provides the basis for analysis.



Shoe box — V(2) = .5993; fan 10°,20°,30° — V(2) = .5922, .6157, .6092; Roman — V(2) = .4986; Diamond — V(2) = .5991

fig. 12 Desirability values of different auditorium geometries.

9. MICRO-ANALYSIS, the desirability of the seating plan.

Within the framework of an auditorium plan the seating can be arranged in a number of different ways. The auditorium must have aisles, and the seats will have to be of a certain size. The desirability value of the seating plan is therefore best calculated as the average desirability value per seat. The micro analysis evaluates the average desirability value per seat of the actual seating plan. $V(3) = \Sigma v / S$, where S is the number of seats.

The actual desirability value of the seating plan of Odense Koncerthus is calculated to be V(3) = 0,6622. Had the seating plan been laid out according to the 'Continental Seating Plan', (30 rows of 40 seats, area allocated per seat 100*62) then the desirability would have been increased to: V(3) = 0,6858. 'The Continental Seating Plan' takes advantage of placing seats in the part of the auditorium which has the highest desirability value, namely along the center line. In Odense this area is allocate to aisle space. The area allocated per seat in the 'Continental Seating Plan' is slightly increased in depth following code regulations in the USA. The increased area allocated per seat will also result in potentially more comfortable seats. This will further increase the desirability value of the seats.

I have made a detailed study of 'The Continental / Conventional Controversy' as well as 'The Comfort / Space Efficiency Trade-off', but that research is beyond the scope of this paper.

10. REFERENCES

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