

Design Evaluation and Strategies: the case of University Auditoriums

Doris C.C.K. Kowaltowski, Silvia A. Mikami G. Pina, Stelamaris R. Bertoli and Carolina Soler

Department of Architecture and Building, School of Civil Engineering, Architecture and Urban Design, State University of Campinas, UNICAMP
Caixa Postal 6021, 13083-852, Campinas, SP, Brazil, phone: +55 019 37882390,
Email: doris@fec.unicamp.br

ABSTRACT: This paper presents a study of auditorium spaces in Universities, with a seating capacity of 300 to 400. The study verified the design procedures adopted by architects and consultants. Building performance was assessed through technical measurements and questionnaires applied in two auditoriums. Evaluation results showed that areas reserved for circulation and sight lines are not ideal in the two auditoriums, but the intelligibility of the rooms and thermal and artificial lighting conditions were good, although users complained about low temperatures. Thermal comfort was shown to depend exclusively on air-conditioning in the local hot and humid climate and the audio-visual requirements of such auditoriums.

The study also showed that the design process is complex and needs to address a large number of variables (sight lines, circulation, accessibility and evacuation, effects of artificial lighting, speech intelligibility, air-conditioning). Acoustics is a major issue and consultants have an influence on design solutions. The study demonstrated that specific design strategies should be adopted to assure design quality for auditorium spaces. Building Performance Assessment (BPA) data and a good design repertoire can guide the decision making process. An outline of a method is presented based on MEHTA, JOHNSON e ROCAFORT (1999).

Keywords: Auditorium, design strategies, building design assessment, environmental comfort

1. INTRODUCTION

Multipurpose auditoriums are considered noble spaces in buildings. Their design, construction and use phases need to give special attention to a large variety of aspects. The design team should consist of professionals representing different areas of expertise, to guarantee the environmental quality demanded by clients and users. The literature on auditorium design primarily addresses acoustics and architectural criticism emphasises aesthetic and formal aspects [1 - 7].

The design process of auditoriums must take into consideration functional aspects of the foyer, the audience space itself, the stage and the support rooms. The architectural program must address not only functional but comfort, technical and aesthetic aspects of the design. An auditorium generally fulfils many purposes within the building complex of a university. Auditoriums can be important as classrooms, in specific faculty areas, or serve ceremonial occasions in a central position of campuses.

The design process of auditoriums usually emphasizes the orator (stage) and the listener (auditorium) but must take into consideration the context and flexibility of multiple uses. Data supplied by the client such as capacity, budget and priorities must be analyzed. In university auditoriums the

spoken word is considered a priority. Architectural questions of form, volume, and dimensions need to be addressed at an early stage, since these affect speech intelligibility. Multiple uses, which range from lectures to theatrical and music performances, are difficult to achieve in a quality auditorium design, because acoustic requirements are distinct. Escape routes and accessibility considerations are further important design matters to be analyzed.

This paper presents a study on the design process of university auditoriums using as a starting point the method presented by MEHTA, JOHNSON and ROCAFORT [8 p. 218] shown in figure 1. Common practices and actual spaces were analyzed to develop a design procedure, which includes audiovisual, lighting, thermal, seating, technical equipment and maintenance considerations for the local Brazilian university application. To develop this procedure two lecture halls were analysed, nine architects were interviewed and five international theatre design specialists answered questions on technical details.

2. COMMON DESIGN PROCEDURES

A study of common practices in Brazil showed that the initial phase starts with the architect's contact with the client. The overall design concept is quickly reached by the principal author. Consultants enter into the picture for specific assistance. Mainly acoustic

considerations are left to specialists and their participation is reduced to a minimum to control costs. Architects emphasize their control over design decisions, seeing specialists as technicians and not as full design team members.

Building performance assessment (BPA) is not a common practice for troubleshooting and design feed back. Such post occupancy evaluations can generate important data to improve future designs and correct imperfections in buildings under construction. Simulations can be performed to gauge design decisions, such as sight lines, energy consumption and lighting conditions.

In local procedures the architectural program is often only a list of rooms and their capacity, with little detailing in relation to architectural and technical performance specifications. To contribute to the discussion of design processes and accumulate important building performance data two university auditoriums, with a seating capacity of around 350, were evaluated.

3. PERFORMANCE ASSESSMENT

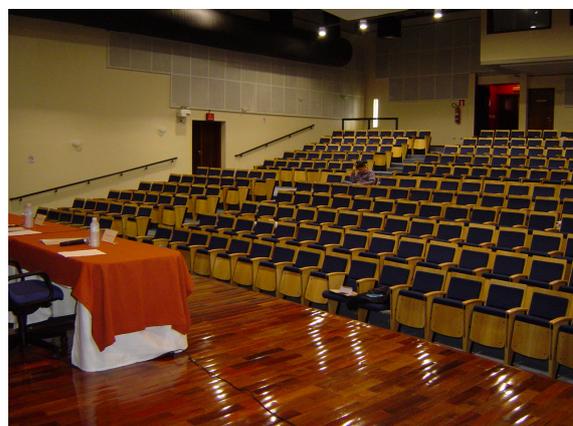
The environmental performance of two University auditoriums "Dom Gilberto" Lecture Hall of the Catholic University of Campinas, PUCAMP with 410 seats and the Auditorium of the Medical School of the State University of Campinas, UNICAMP with a 300 seat capacity, as shown in figure 2 were evaluated. Both universities are in the city of Campinas, in the State of São Paulo in Brazil. They are therefore exposed to similar climatic and social conditions.

Technical data was collected from drawings and measurements taken on site. The measurement points are indicated in the lecture hall plans of figure 3. Questions of security and evacuation of people, as well as the circulation conditions were analysed through measurements of aisle dimensions, slopes of ramps, area reservation for wheel chairs and obese users, presence of grab bars, height and depth of steps, indications of exits, types of pedestrian flows and their distribution in and around the auditorium. The visibility of the stage was analysed through user comments and analysis of section drawings. User satisfaction was obtained through a questionnaire application on a seven point semantic scale to 10% of the seating capacity in each space.

Since both spaces are air-conditioned thermal comfort was measured on a single occasion with digital equipment to assess humidity, globe and air temperatures (SKL200th-SATO and TGD-100, Instrutherm). The users assessed the ventilation conditions and temperature sensations. The thermal comfort conditions were calculated as estimated satisfaction rates through the use of a simulation program (Comfort 2,02, [9]). User activity was considered as the equivalent of "1 met" and clothing was defined as "0,6 clo", representing typical clothing of students at the local universities. Air velocity was defined in 0,1m/s, commonly found in closed air-conditioned spaces. Factors of air quality, such as air exchange rates, provision of oxygen, and removal of excess CO₂ were not assessed in this study.



"Dom Gilberto" Lecture Hall - Catholic University of Campinas, PUCAMP

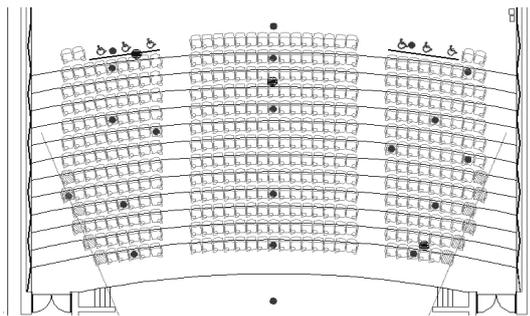


Auditorium of the Medical School of the State University of Campinas, UNICAMP

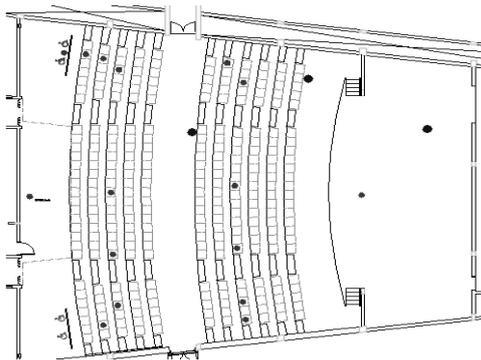
Figure 2: Views of the auditoriums assessed

Acoustic conditions were measured with a Bruel & Kjaer sound pressure analyser (model 2238-D). A frequency of 63-8.000 Hertz, in three systematic measurements was used to verify the average of the variations. Three distinct situations were evaluated: 1. empty auditorium with the air-conditioning system turned off; 2. empty room with air-conditioning on and 3. the room in use. A speech intelligibility test was also performed in the two lecture halls and reverberation times were calculated according to MEHTA, JOHNSON and ROCAFORT [8] and measured using equipment (Brüel & Kjaer, BZ 7204 and sound amplifiers models 2716, 5296 and 2260).

Lighting conditions were evaluated through measurements of "lux" levels in various points at a height of 0.60m from the floor with a digital luximeter (Instrutherm, model LD-206). Two distinct situations were defined: lighting for a lecture and reduced lighting for projections of "data show" images and videos. Natural lighting was not considered.



Plan of the "Dom Gilberto" Lecture Hall



Plan of the Auditorium of the Medical School

Figure 3: Indication of points of technical comfort measurements (dots) (small=acoustics, larger=thermal).

3.2 Assessment Results

The "Dom Gilbert" Auditorium (PUCCAMP) was inaugurated in 2002 as a general lecture hall for the university. Only one main entrance/exit door leads to the auditorium space, which interferes with circulation flows. The lack of a foyer is perceptible since natural light enters the room directly when users open the door, interfering with the visibility conditions of the auditorium. To comply with fire safety regulations two emergency-exits are located near the stage, which are properly marked and are equipped with panic bars. However the 1,20m wide aisles are on slopes and no level resting areas are introduced prior to the emergency doors, which may cause some problems with evacuation of the hall in case of a fire, for instance. The lateral aisles lack grab bars for safety. The predominant gray colour scheme also confuses the circulation of users, since it is difficult to distinguish steps from ramps.

The auditorium seats are placed on irregular dimensioned steps. This condition interferes with uniform sight lines. Since the distance of the stage to the last row is only 13m visibility is however generally good. The accessibility code [10] is complied with in relation to the slope and width of ramps; however wheel chair areas are only reserved at the back of the hall and users with disabilities are not integrated into the general audience area.

The room is rectangular in shape. To eliminate the parallelism of the space acoustic reflectors are placed along the walls and in the back of the room. The intelligibility test showed the room to have an excellent condition. The noise criterion was based on the Brazilian code [11]. With the air-conditioning off the

room complied with this regulation, but with the system on, the hall complied only just at the limits of acceptable levels (NC 45). The reverberation time measured at 0.7 to 1.0 seconds, but at a frequency of 63 Hz, which is a little below recommended standards.

Thermal comfort conditions showed a variation of air temperatures between 23,7°C and 22,1°C which indicates that an airflow or distribution problem exists. Relative humidity also presented variations from 51,8% to 60.0%. The estimated mean satisfaction rates, calculated according to the measured conditions, showed, in some points, that 40% of users would not be satisfied.

The visibility curve is good in the whole of the auditorium, but the first two rows have difficulties in seeing focal points at a height of 40cm on the stage. The general lighting quality was assessed and possible undesirable reflections and safety lighting were observed. Stage lighting measured at between 110 and 207 lux, thus below recommendations of the local code [12], which establishes levels from 250 to 500 lux for the seating area and 500 to 1000 lux for the stage. Moreover some reflection problems exist, because of the shiny floor material used in aisles.

The Medical School auditorium of UNICAMP was inaugurated in 2002 as a ceremonial and conference space. It is mainly used for lectures and graduation ceremonies. The lecture hall has a capacity for 300 people and an area reserved for 4 wheel chairs in the back of the room. The general public enters the hall through a foyer with two distinct entrances and antechambers, which avoid light from the foyer invading the audience space. Two emergency exits are situated at the front and a projection cabin is located at the back of the room. Exits do not possess anti-panic bars.

Seats are arranged in six groups, with two lateral corridors and a central section divided by further aisles. Aisles are not aligned and vary in width to accommodate the curved seating arrangement. The narrow (0.85m) side aisles do not comply with minimum dimensions set by the local fire department. The corridors have steps of varying heights, which may interfere with the flow of people. Emergency lights are properly located in the hall and fire extinguishers are also well identified. The collapsible seats are considered important, in case of an emergency, by increasing the distance between rows. The visibility curve of the hall is also adequate; however objects below 1m height on the stage are not visible from the back of the room, since sight lines intersect. Also, the first two rows are very low in relation to the stage. The dimensions (18m depth) of the room are within the recommended depth for good visual perceptions of images on the stage and establishing a good communication with an orator.

The sidewalls of the room are not parallel; this condition improves acoustics of the hall. Furthermore acoustic reflectors are placed on the stage and at the back of the room. The intelligibility test was excellent in this auditorium as in the previously detailed evaluation. The reverberation time measured above that recommended by MEHTA, JOHNSON and ROCAFORT [8]. At frequencies of 125, 250 and 500 Hz the reverberation time was higher than at

frequencies of 1, 2, 4 and 8KHz. All the averages were above 1.0s. The noise level assessment shows the room has adequate conditions with the air-conditioning system off, however with the system on noise levels are above NC 45 (the acceptable limit) for verbal communication.

Thermal comfort registered temperatures of 23 °C with a 2,2°C variation between measuring points. The airflow is well distributed in the audience and stage areas but relative humidity showed variations from 52,5% to 60%. Thermal comfort satisfaction rates were calculated, reaching again, as in the previous hall, an assessment of 40% dissatisfaction. This index is not ideal.

Lighting conditions were analysed through observations and measurements. Different lighting systems exist for security, emergency, the stage and the general seating area. "Lux" levels measured from 186 to 385 lux, thus below the recommended levels of 250 to 500 lux. Image projection is not ideal since the screen is placed at the back of the stage and the surface is a beige tone interfering in the true reproduction of colours.

3.3 Questionnaires Results

65 questionnaires were applied in both halls corresponding to 10% of the seating capacity. User data showed that most people (65%) are satisfied with the comfort conditions of the rooms, but users also made suggestions to improve specific conditions. Thus, in the "Dom Gilberto" hall better seats were requested and dimensions between rows were considered inadequate by only 4% of users. The interfering light from the foyer was noted by 36% of users questioned. 68% of users considered the room to be cold. This may be due to the lack of air-conditioning in the foyer and the temperature difference between exterior and interior areas, causing a temperature shock situation when entering the lecture hall. Also the auditorium is located in a tropical region with users adapted to fairly high outdoor temperatures during the day most of the year. Around 10% of users asked for the lighting level to be increased on the stage for better visibility of the orator. External noise interfering inside the room was noted by 10% of people questioned, but the lack of an antechamber was not identified. Only 4% of users asked the foyer to be air-conditioned.

The medical school auditorium of UNICAMP was also considered too cold by 36% of people questioned. Users complained about the sonorous conditions of the room, with 48% of people complaining about the air-conditioning noise. 20% of users considered the projection screen too small and 4% asked for more comfortable seats with a writing area accessory. The lighting levels in the hall were considered low by 36% of responses.

4. A DESIGN STRATEGY PROPOSAL

Auditorium Design procedures, as found in the literature, mainly address acoustic specifications and detailing. One such strategy can be found in MEHTA, JOHNSON and ROCAFORT [8] as shown in figure 6. Interviews with specialists and designers with a large experience in auditorium design were held and the

strategy of figure 1 was expanded to address the large variety of aspects that should be considered in the design process of an auditorium. Twenty-eight items can be listed as specific design parameters as follows:

1. Collect design references (literature search).
2. Define the type of auditorium (type of uses, capacity, budget) also discuss the general form of the auditorium (Arena, Elizabethan, Italian or other)
3. Select specific design repertoire corresponding to the type of space chosen.
4. Analyse technical data of the repertoire chosen, especially Building Performance Assessment data.
5. Collect local data for preliminary design (building codes, zoning restrictions, general site conditions, climate data, noise conditions of the site, fire code, accessibility regulations, sanitary codes and environmental comfort recommendations and codes).
6. Adjust general data to client specifications:
 - a. measured external noise
 - b. set internal noise levels
 - c. determine site area
 - d. relate auditorium to the total building complex
 - e. other specific design considerations
7. Define the architectural program:
 - a. Activities
 - b. Type of users
 - c. Capacity of spaces
 - d. Equipment and furniture
 - e. Dimensions and area of spaces
 - f. Technical specifications
 - g. Architectural (aesthetic) specifications.
 - h. Space relationships (bubble diagram)
8. Define the preliminary form (volume) of the auditorium and siting conditions:
 - a. Siting, orientation, access (main, emergency, service)
 - b. Consider siting conditions for fire fighting equipment and ambulance access
 - c. Consider acoustic barriers against external noises
 - d. Car parking
9. Detail the seating arrangement of the audience space:
 - a. Consider circulation (number and position of aisles)
 - b. Straight, curved or staggered seating
10. Estimate the recommended area and volume:
 - a. 0.55 – 0.7m² per seat
 - b. 2.0 – 5.0 m³ per seat
11. Determine the final form of the audience space and auditorium:
 - a. Rectangular, "fan" or other shaped
 - b. Check angles of the relation between the form of the auditorium and the seating area (Figure 4).
12. Verify the maximum (25m) distances from last seating row to stage:
 - a. For facial expression – 12m
 - b. Gestures – 20m
 - c. Major body movements – 30m
 - d. If maximum distance is too large, include a balcony and redistribute seats.

- e. Check the height and depth conditions of the balcony to avoid acoustic problems, shaded area in figure 5.
- f. Increase the width of the auditorium if maximum distance is too large

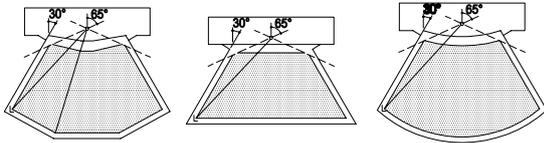


Figure 4: Relation between auditorium form and seating area

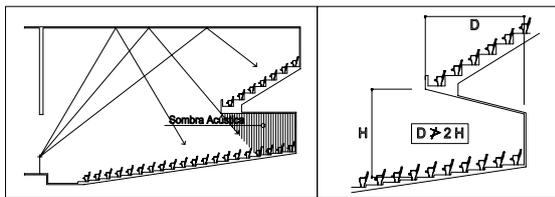


Figure 5: Auditorium balcony conditions

13. Define circulation spaces according to safety regulations, accessibility codes and circulation flow (auditorium capacity, width of aisles, number and location of emergency exits, escape routes, emergency equipment and signs, emergency lighting, smoke detectors, alarm systems, sprinklers, wheel chair areas, inclination of ramps, handrails and floor indications)

14. Specify type of seat (dimensions, colour, material, fixing conditions, resistance, quality and guaranty, accessories, safety)

15. Finalize the form and verify once more angles and distances.

16. Introduce and design reflectors on the ceiling according to acoustic reflections in section drawings.

17. Calculate the volume.

18. Check the relation between volume and seating capacity.

- a. Adjust the acoustic reflector design to the final form and accept minimum acoustic unconformities.

19. Check the length of direct (distance between seat and sound source) and reflected acoustic lines (sound rays). Do they exceed 20m?

- a. Where the distance exceeds, substitute reflectors for absorbing surfaces

20. For the designed volume establish the optimal reverberation time, as indicated on table in Mehta et. al. [8, p. 218] and the necessary absorption of the room, which depend on the volume, type of uses of the room, type of seat and wall, ceiling and floor material specified.

21. Specify the necessary sound absorption of the room starting with the back wall, sidewalls, back of ceiling and finally the front of the room.

22. Define, specify and design the complementary systems:

- a. Air-conditioning
- b. Lighting
- c. Scenic conditions

d. Maintenance and access conditions (galleries).

23. Design auxiliary spaces:

- a. Sanitary facilities (dimension according to audience capacity)
- b. Foyer, café, cloakrooms, ticket office, etc...
- c. Back stage
- d. Etc...

24. Analyse the final acoustic conditions estimating the sound pressure level (NC curves).

25. Define architectural details.

26. Accompany the construction phase.

27. Assess the building performance through measurements, observations and questionnaires:

- a. Acoustic measurements: sound levels, intelligibility and reverberation times.
- b. Thermal conditions: temperatures (wet and dry bulb), air velocity and relative humidity. Distribution of air outlets.
- c. Lighting: level of lighting conditions in different settings, distribution and reflections, emergency lighting
- d. Satisfaction levels of users

28. Introduce "Retrofit" changes if needed.

5. CONCLUSION

This study showed that the design process of auditoriums is complex and needs to address a large number of variables (sight lines, circulation, accessibility and evacuation, effects of artificial lighting, speech intelligibility, air-conditioning). Acoustics is a major issue and consultants influence design solutions. The study demonstrated that specific design methods or strategies should be adopted to assure quality design for auditorium spaces. Building Performance Assessment (BPA) data and a good design repertoire can guide the decision making process. An outline of a method is presented based on MEHTA, JOHNSON and ROCAFORT [8]. This method is expanded to include a more complete list of design issues. These include aspects of: site analysis and planning, legislation and regulations, architectural programme definition (type, capacity and use of space), form and volume, auxiliary spaces, access and circulation (number and width of exits and corridors, escape routes and fire safety, universal design), seating arrangement and choice of seat (type, dimension, colour, materials, fixing details, resistance, accessories and safety), stage configuration, sightlines and maximum distances, lighting, acoustics and air-conditioning details and adjustments. The construction phase needs the close participation of designers and consultants and auditoriums should be tested with retrofit adjustments before their inauguration. Finally BPA data should be collected to close the design strategy cycle.

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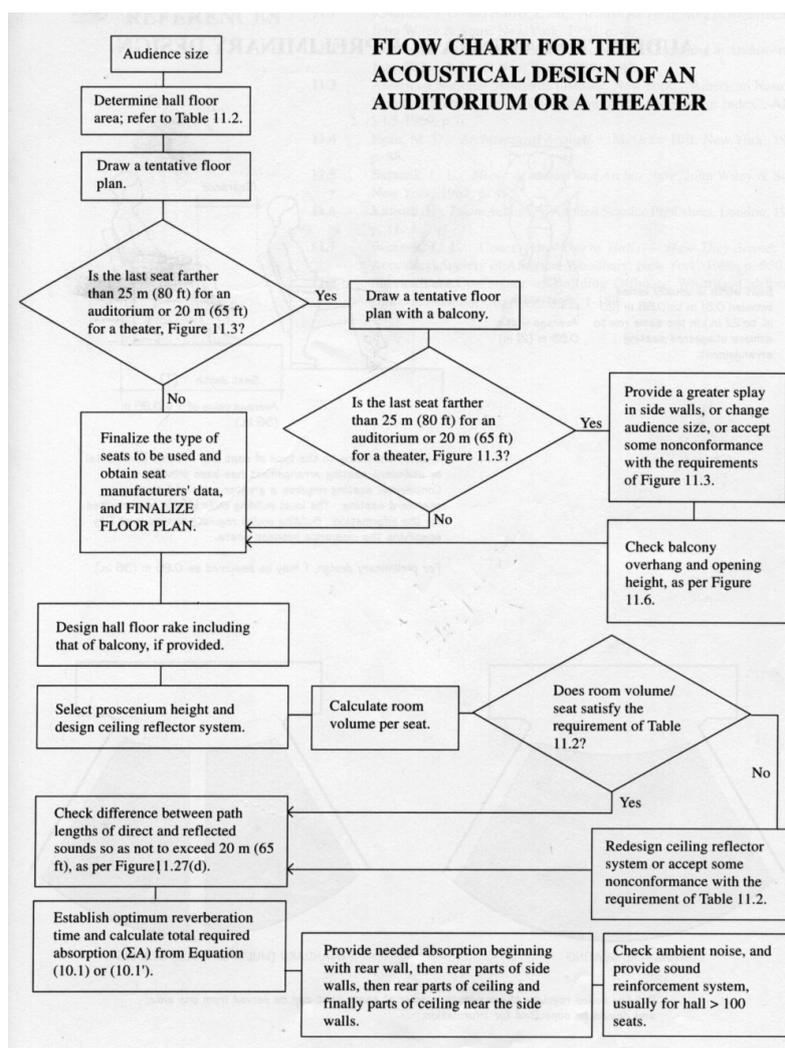


Figure 6. Design strategy [8].