
SYDNEY NATIONAL OPERA HOUSE

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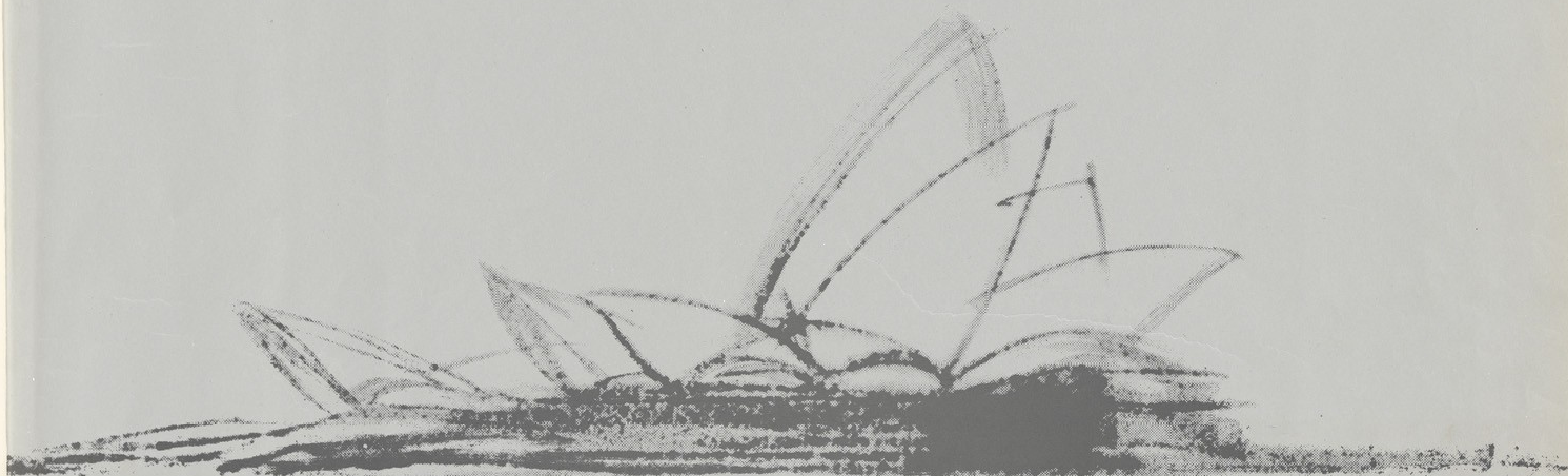
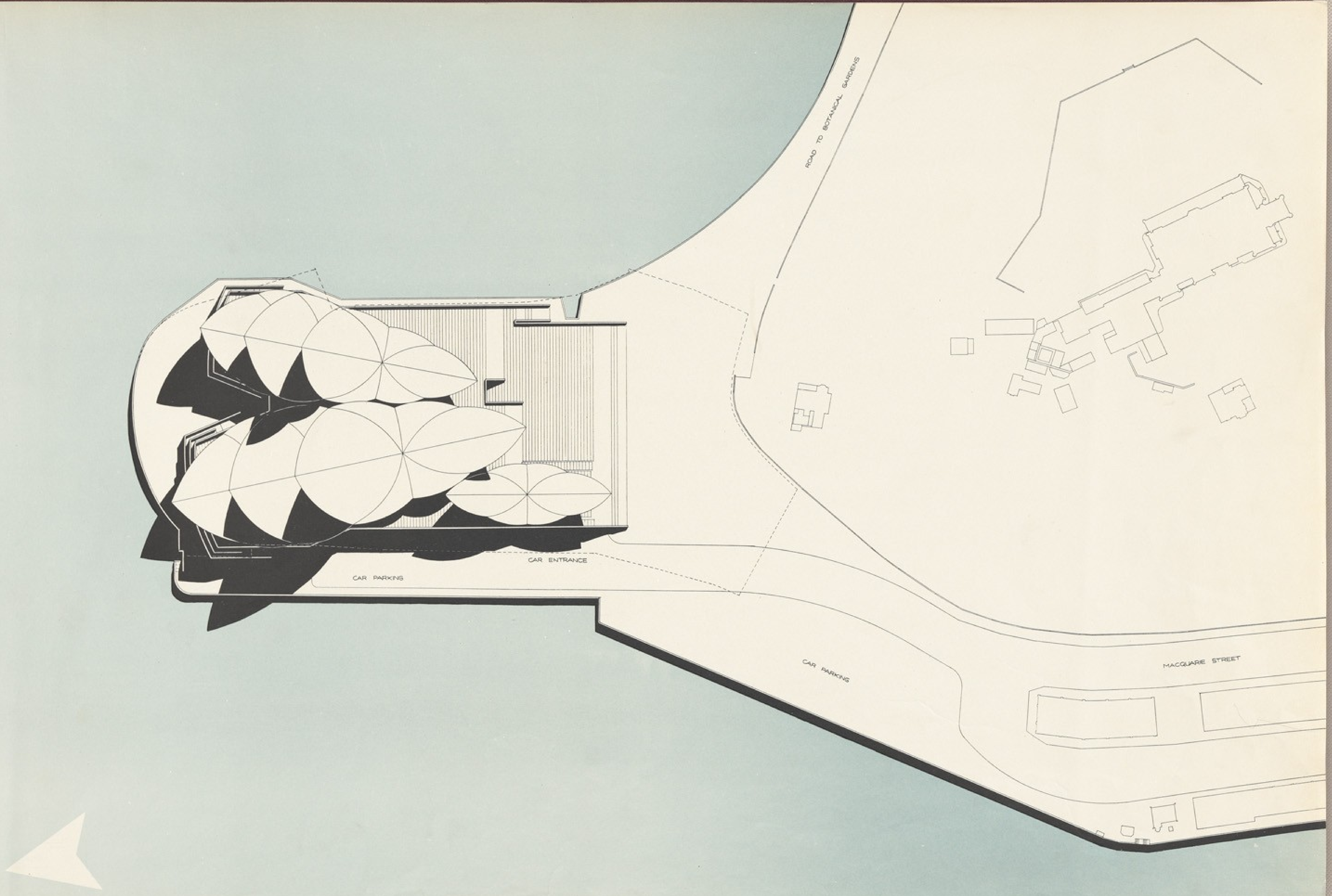
I am happy that with this book I am able to give the Premier, the Right Honourable J.J.Cahill and the Opera House Committee a project which realises in a practical form the vision of the competition.

After interesting and intense work with the various specialists, we are convinced that the far seeing aspirations and efforts of the Committee, sponsors and other supporters of the scheme can be crystallised in a building which, in a functional, festive and inspiring manner will shelter the activities and the life lived within it, and in doing so enhance the face of Sydney.

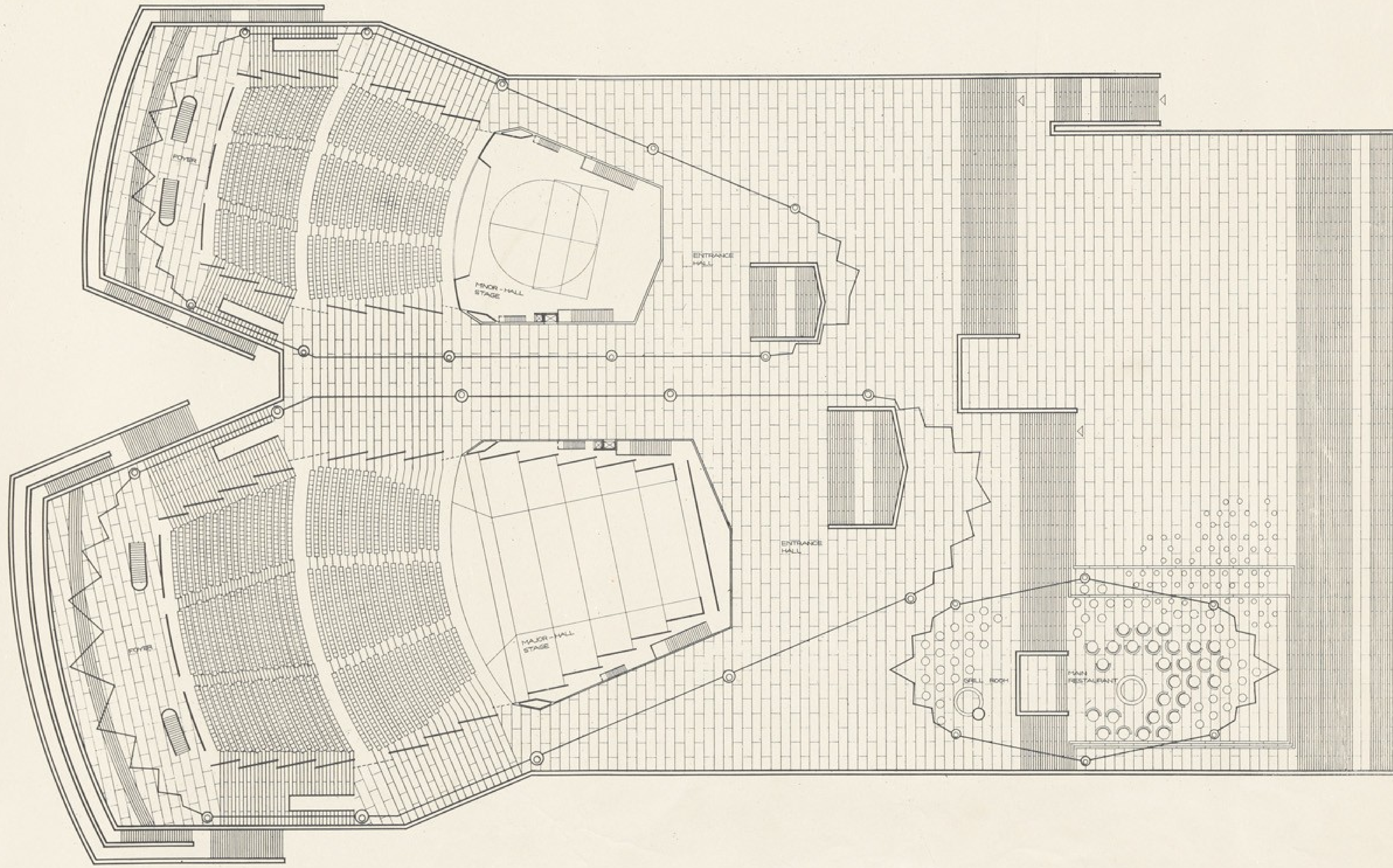
Jørn Utzon

Jørn Utzon
march 1958

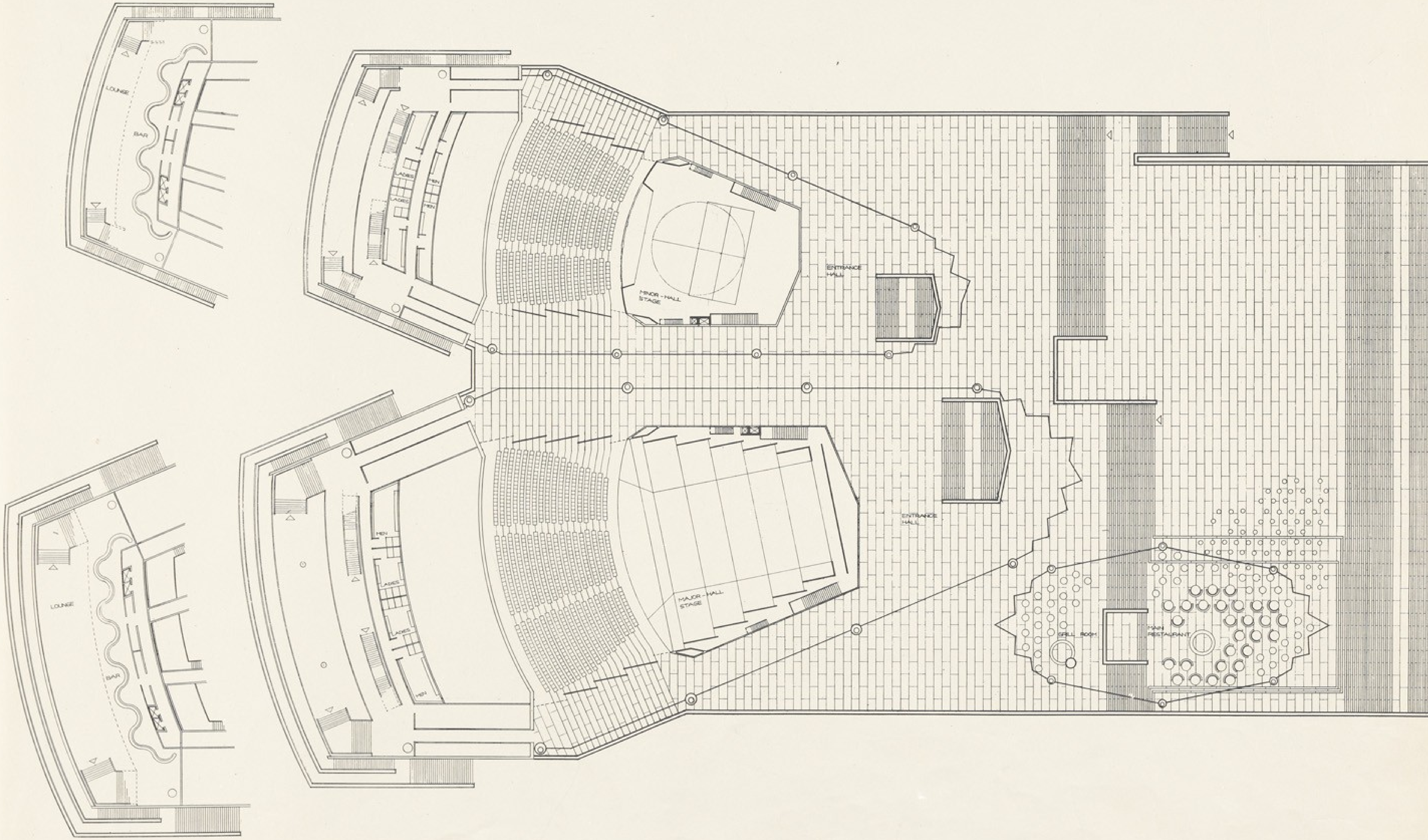




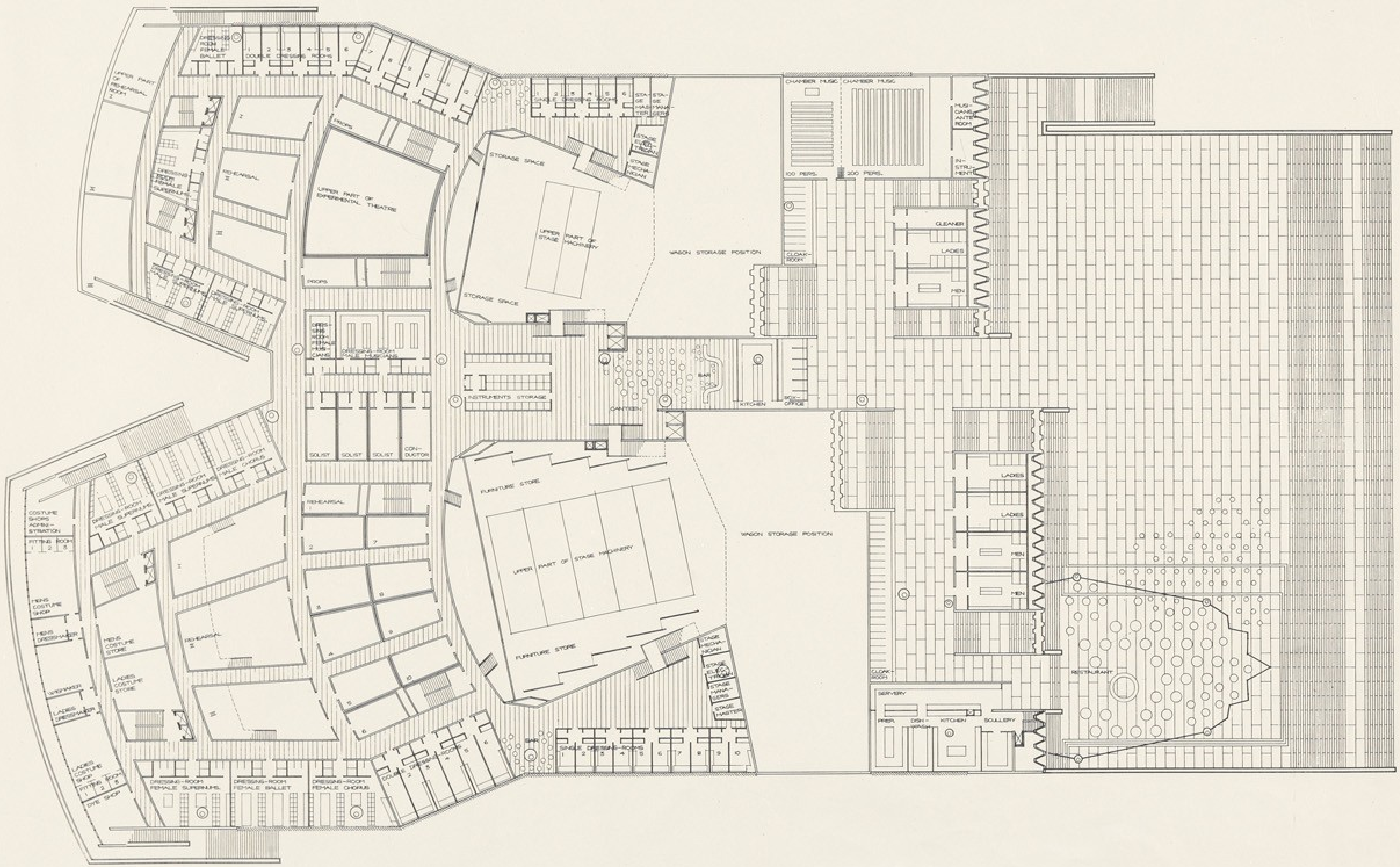
SITE PLAN SCALE 80' = 1"



PLAN OF HALLS SCALE 1/32" = 1'-0"



PLAN OF BARS   SCALE 1/32"-1'-0"



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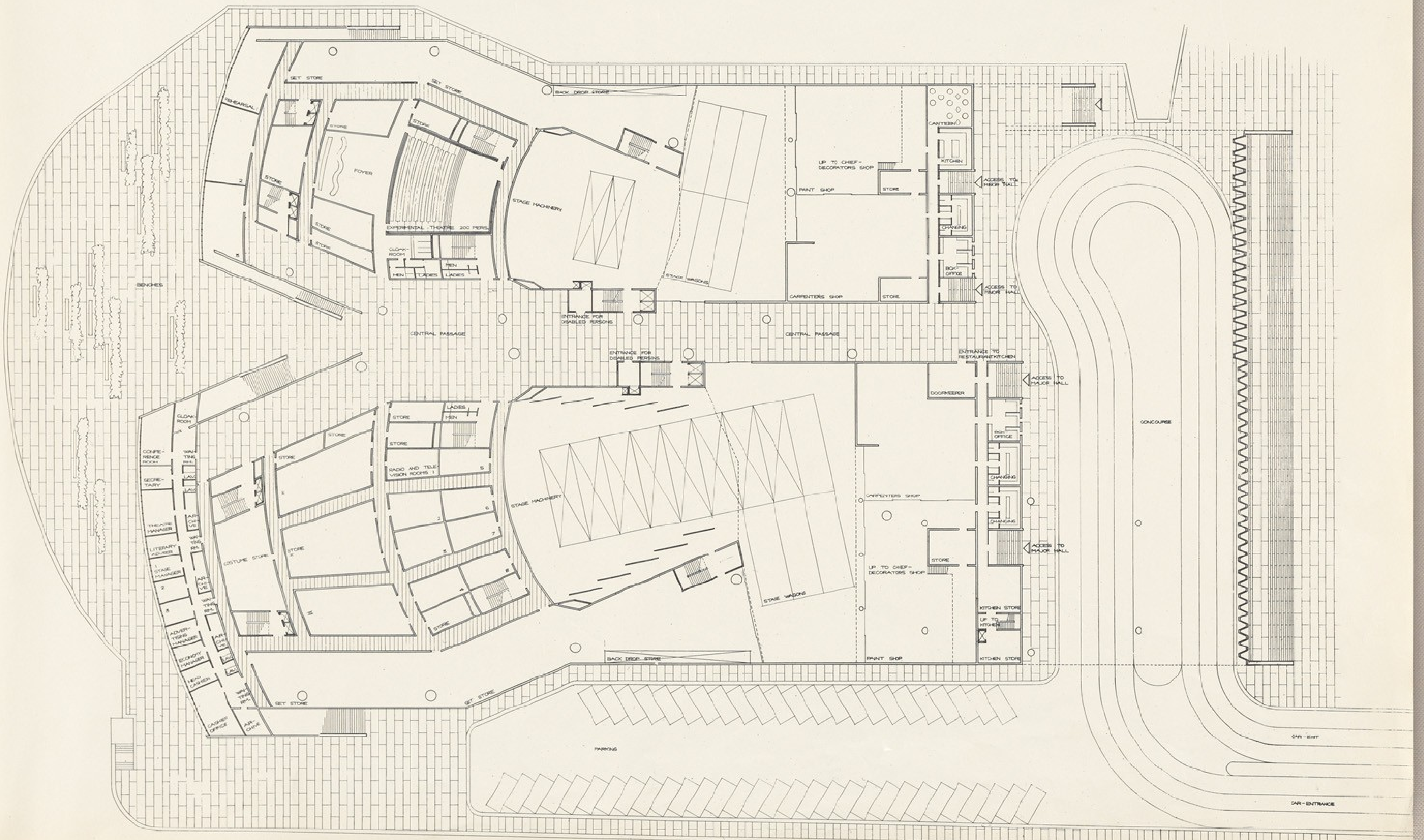

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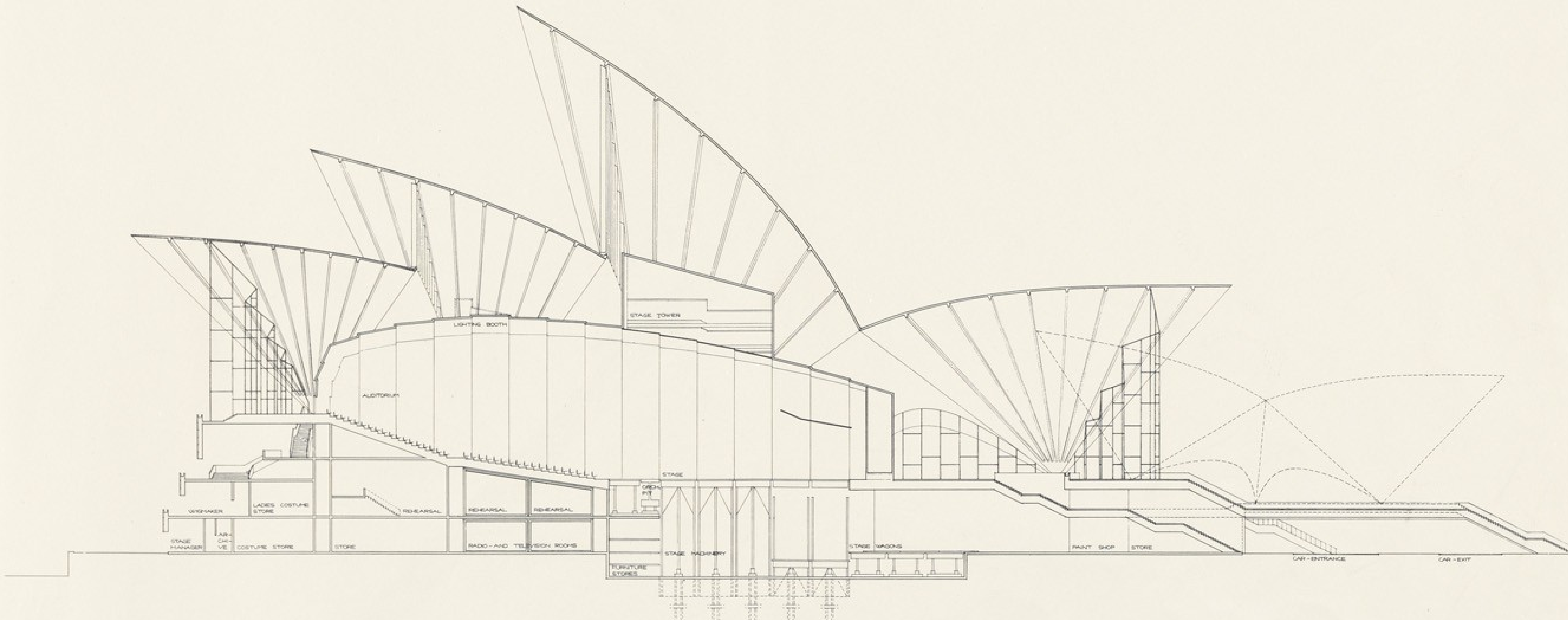
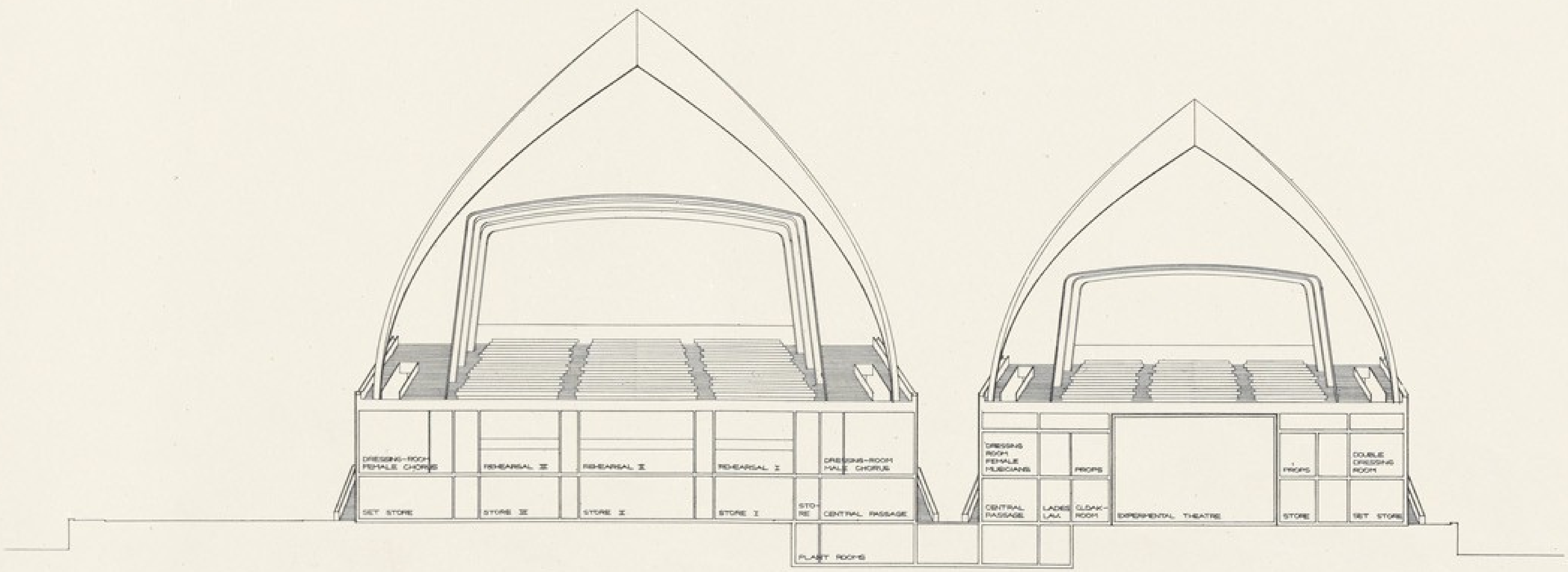
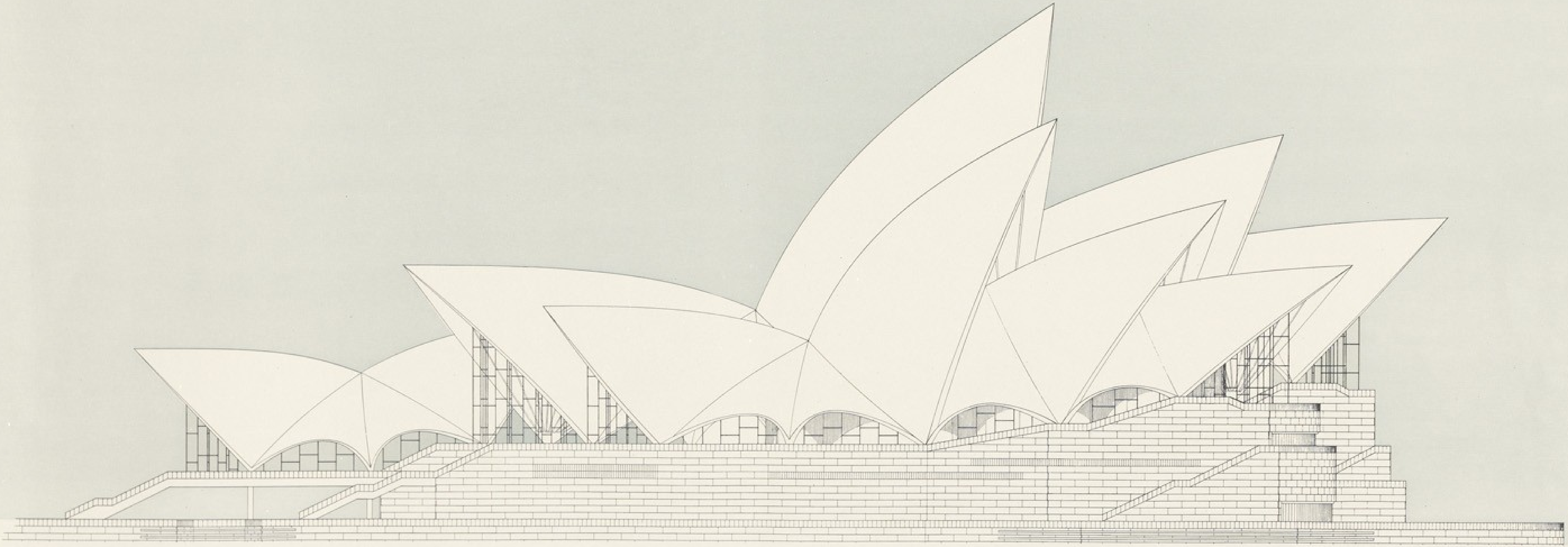


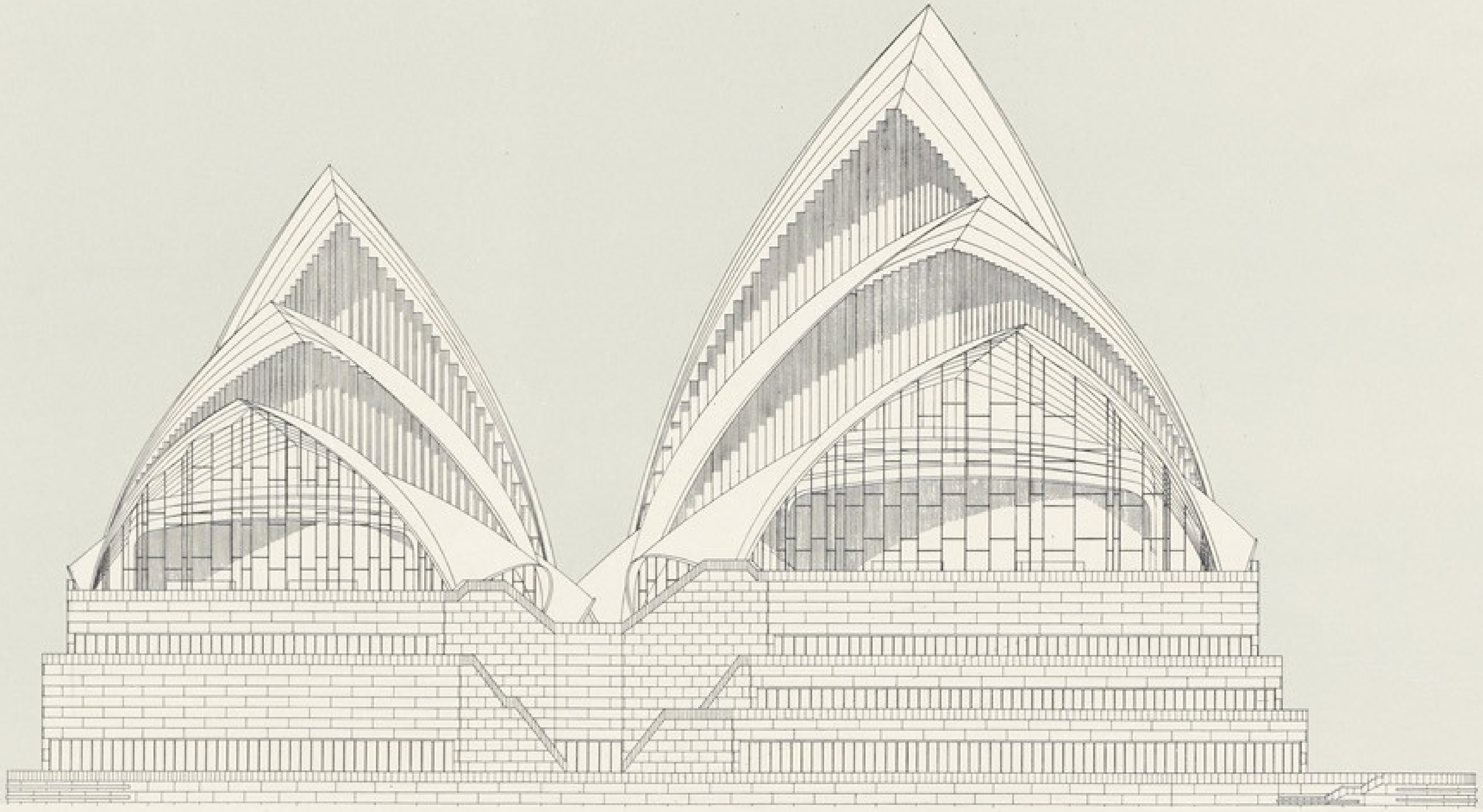
LONGITUDINAL SECTION THROUGH MAJOR HALL SCALE 1/32" = 1'-0"



SECTION THROUGH THE HALLS SCALE 1/32" = 1'-0"



EAST ELEVATION SCALE 1/32" = 1'-0"



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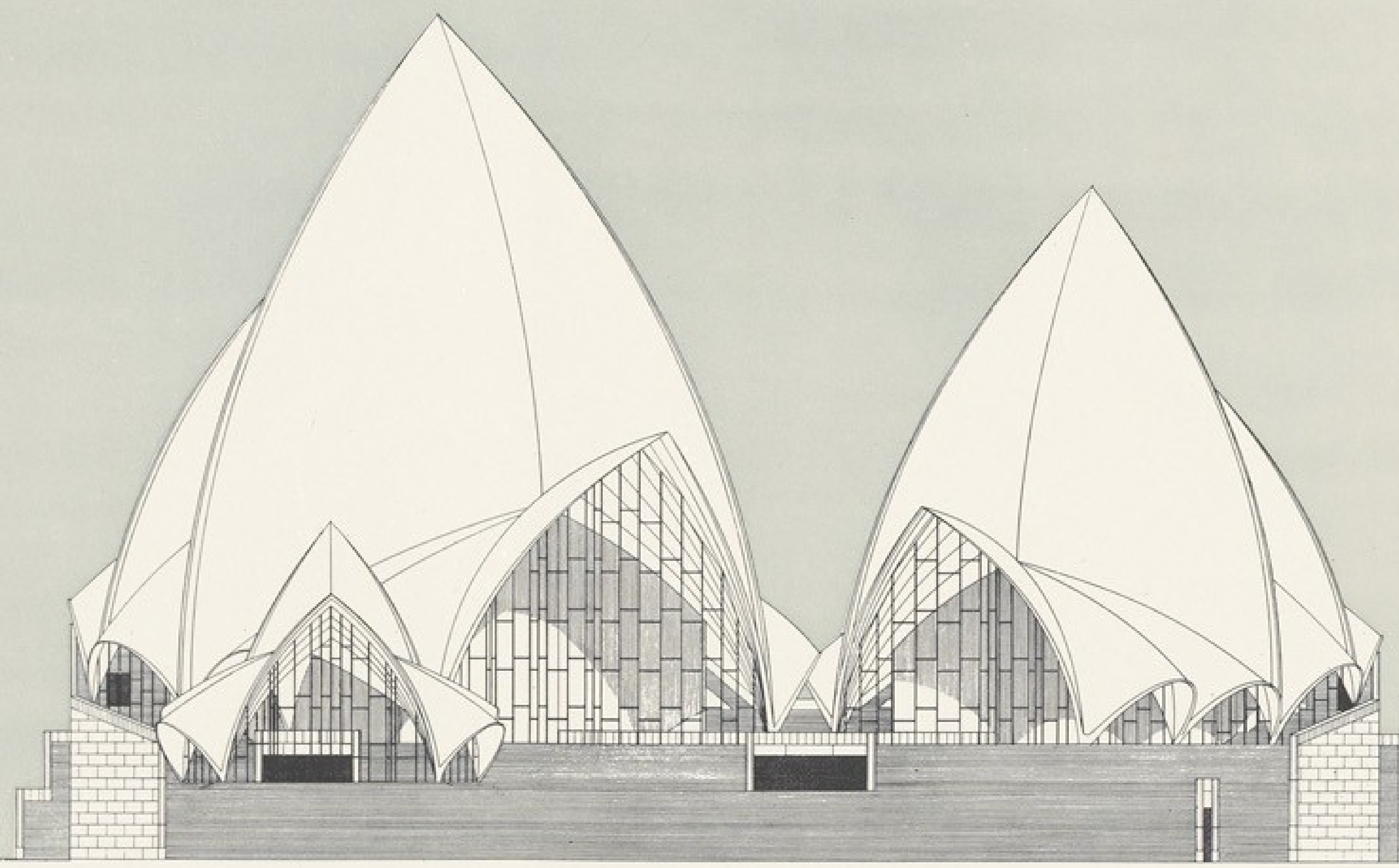
WEST ELEVATION SCALE 1/32" = 1'-0"



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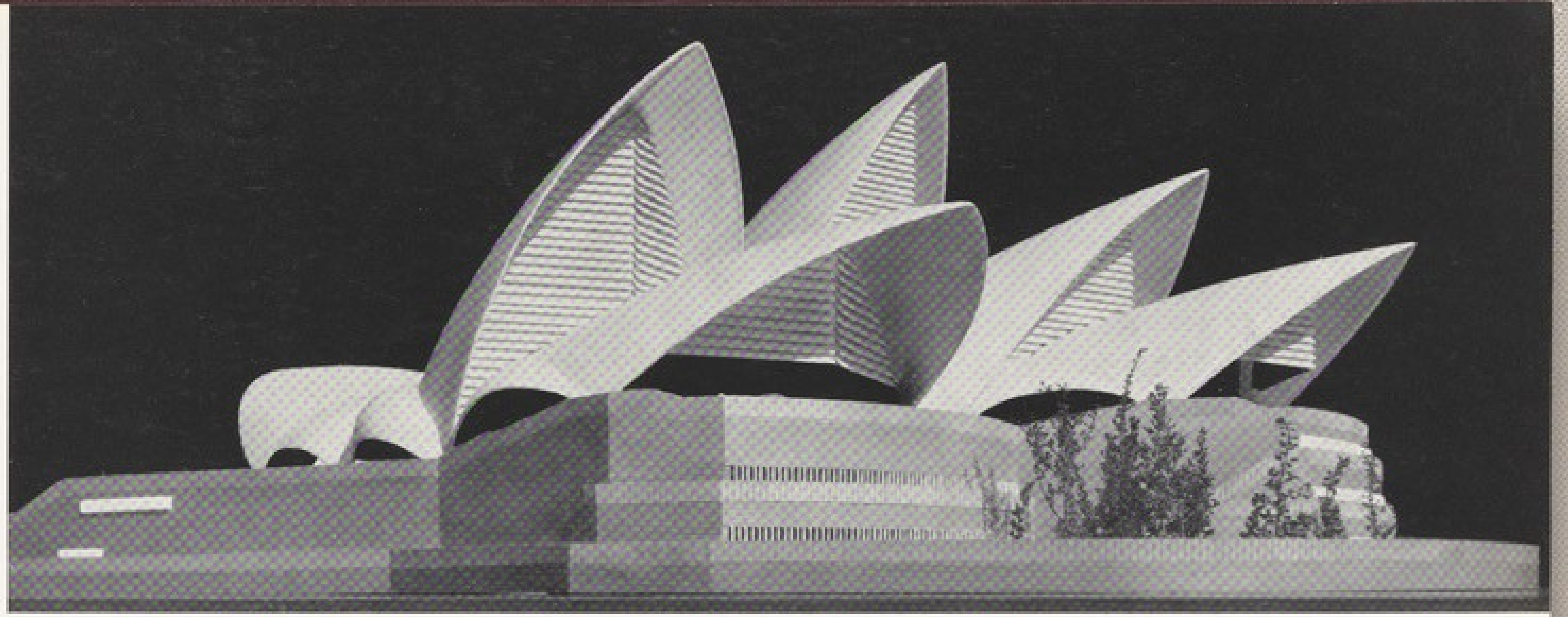
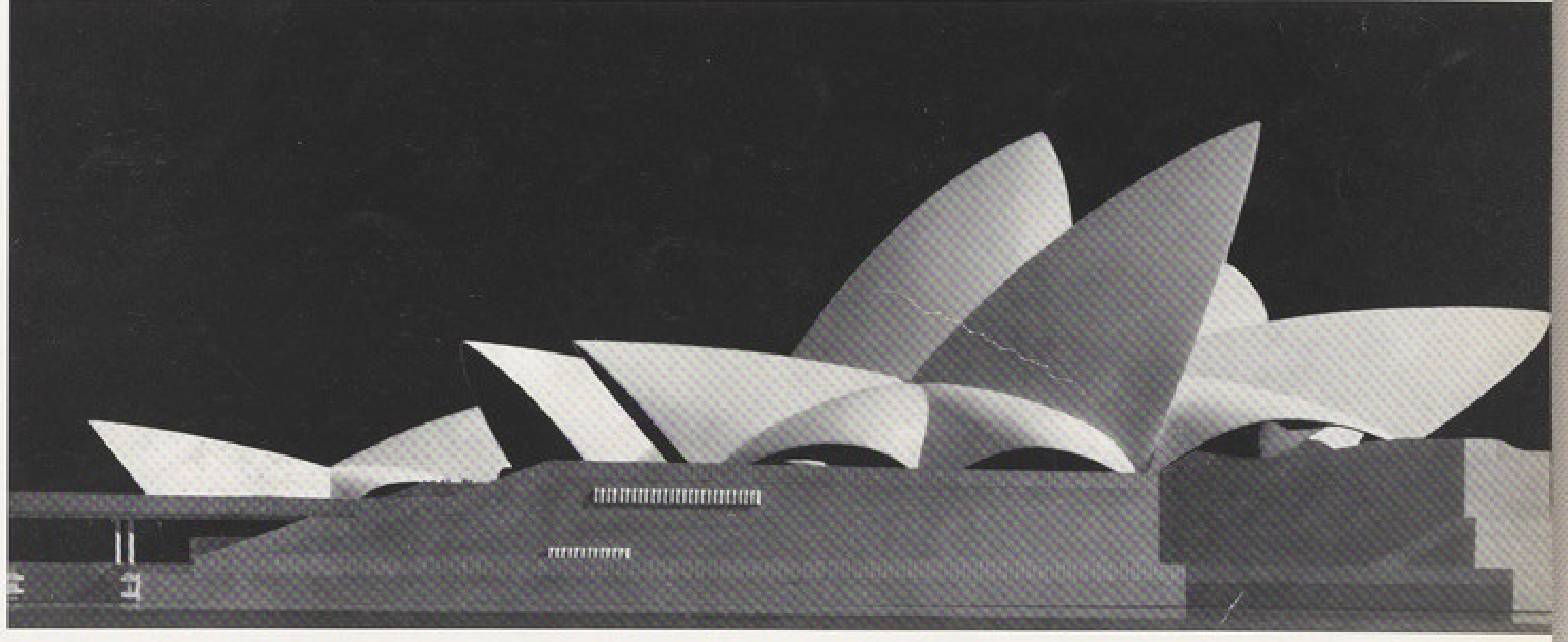
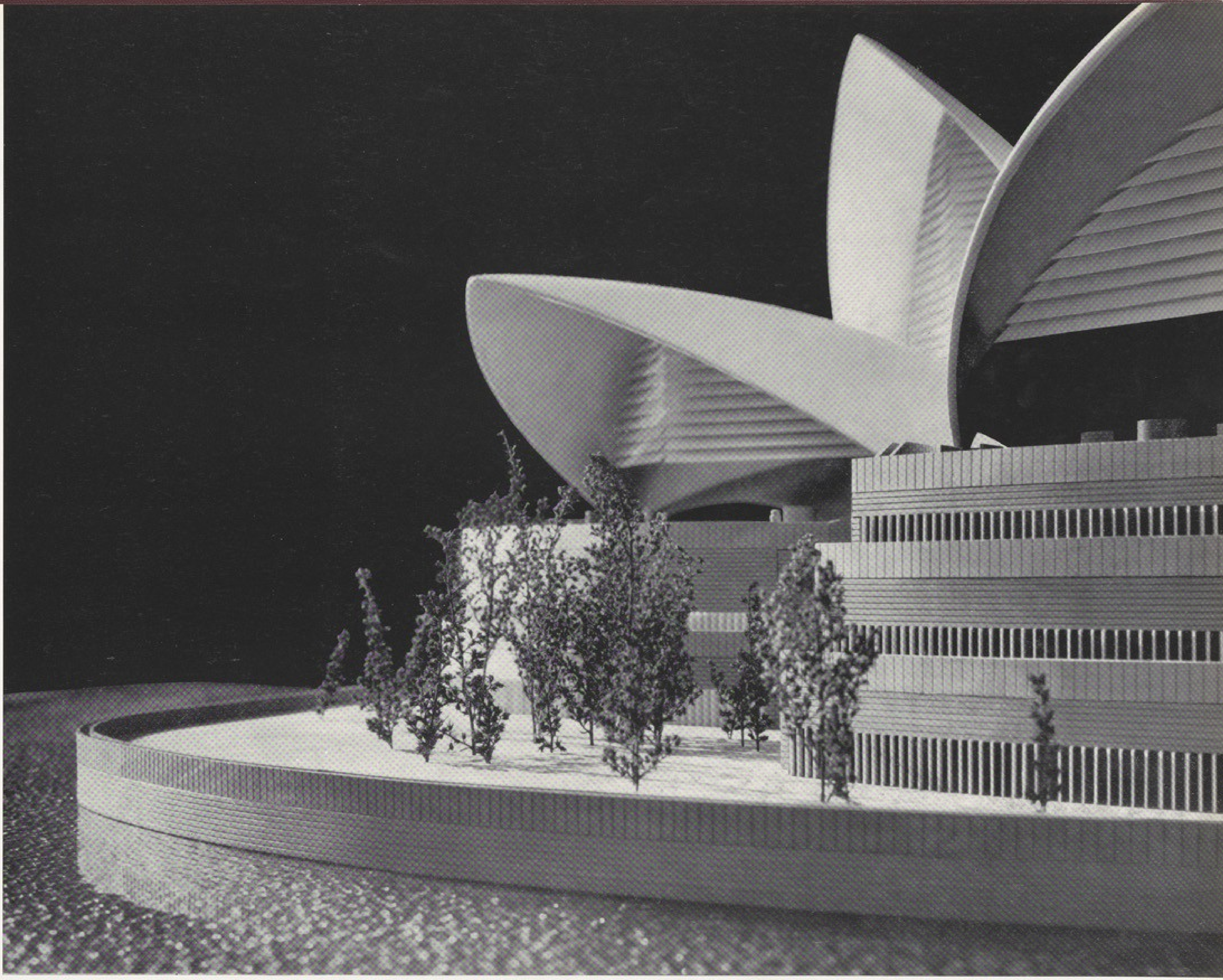
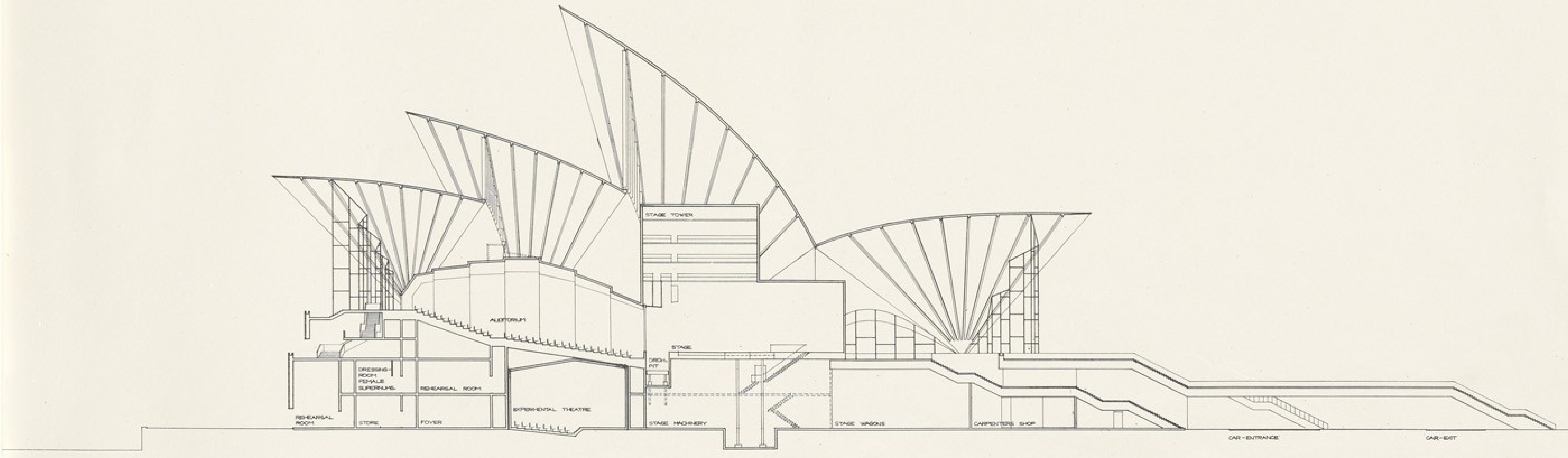
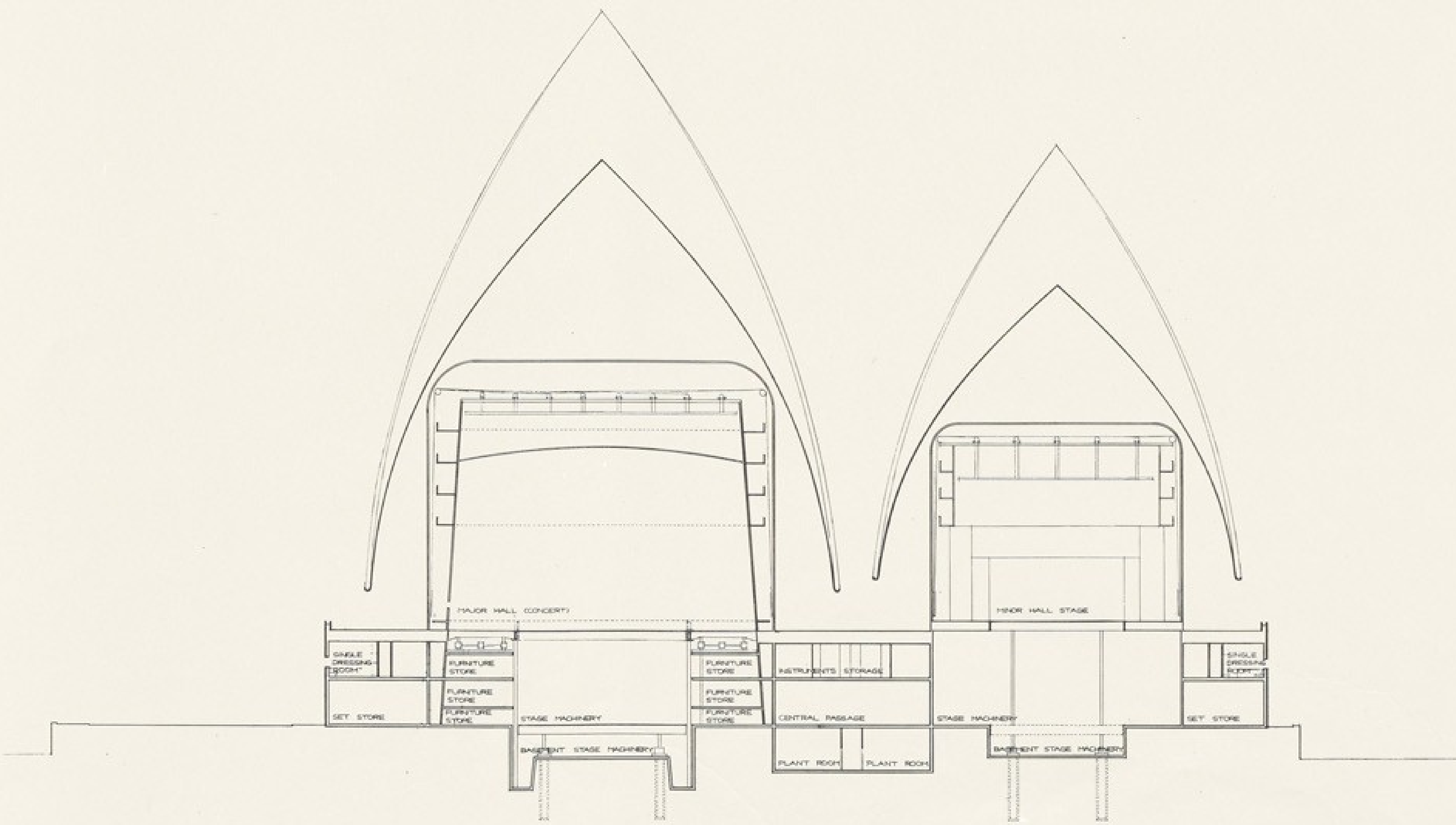




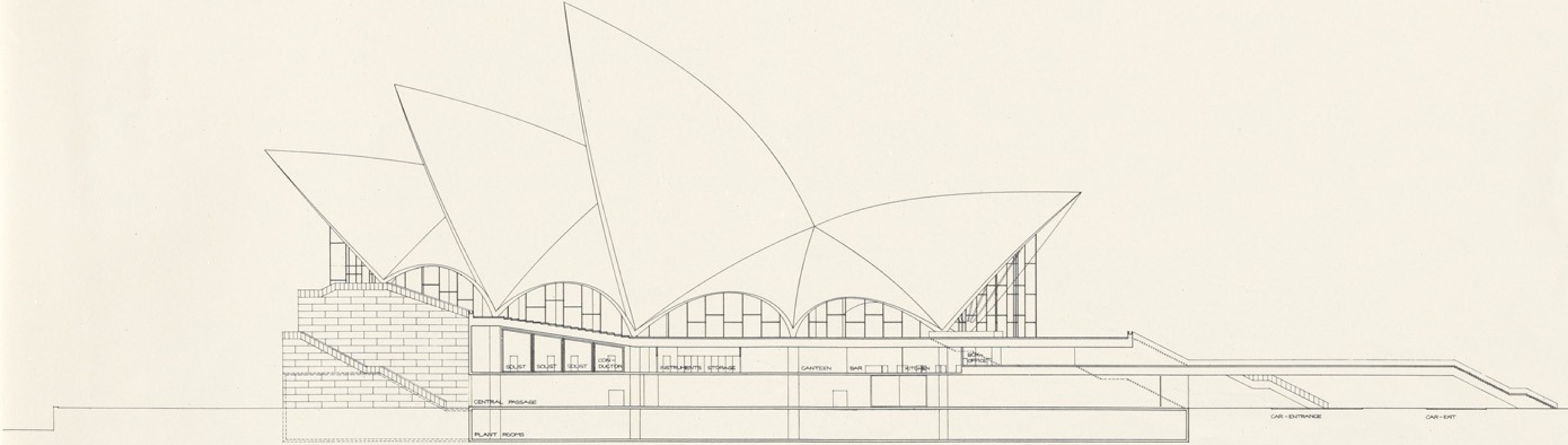




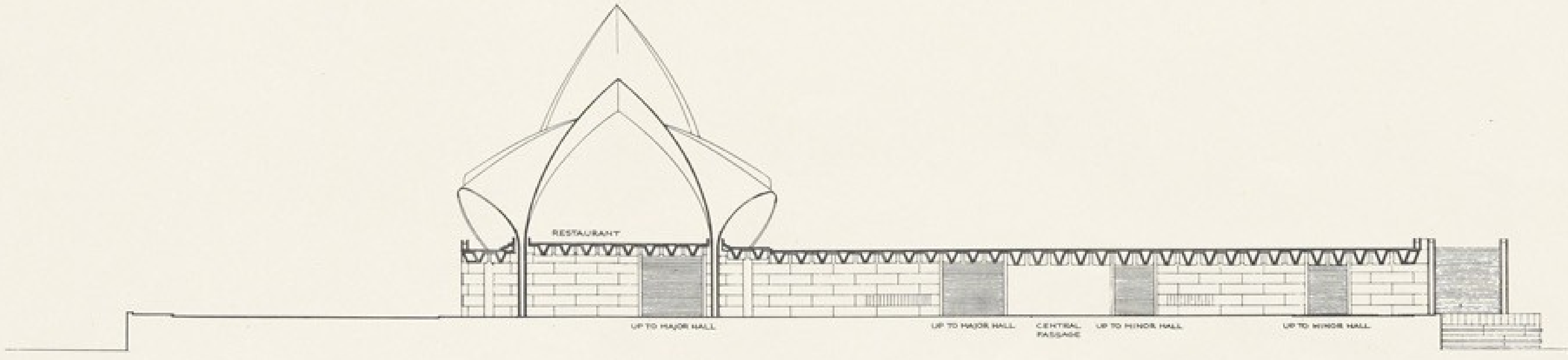
LONGITUDINAL SECTION THROUGH MINOR HALL SCALE 1/32" - 1' - 0"



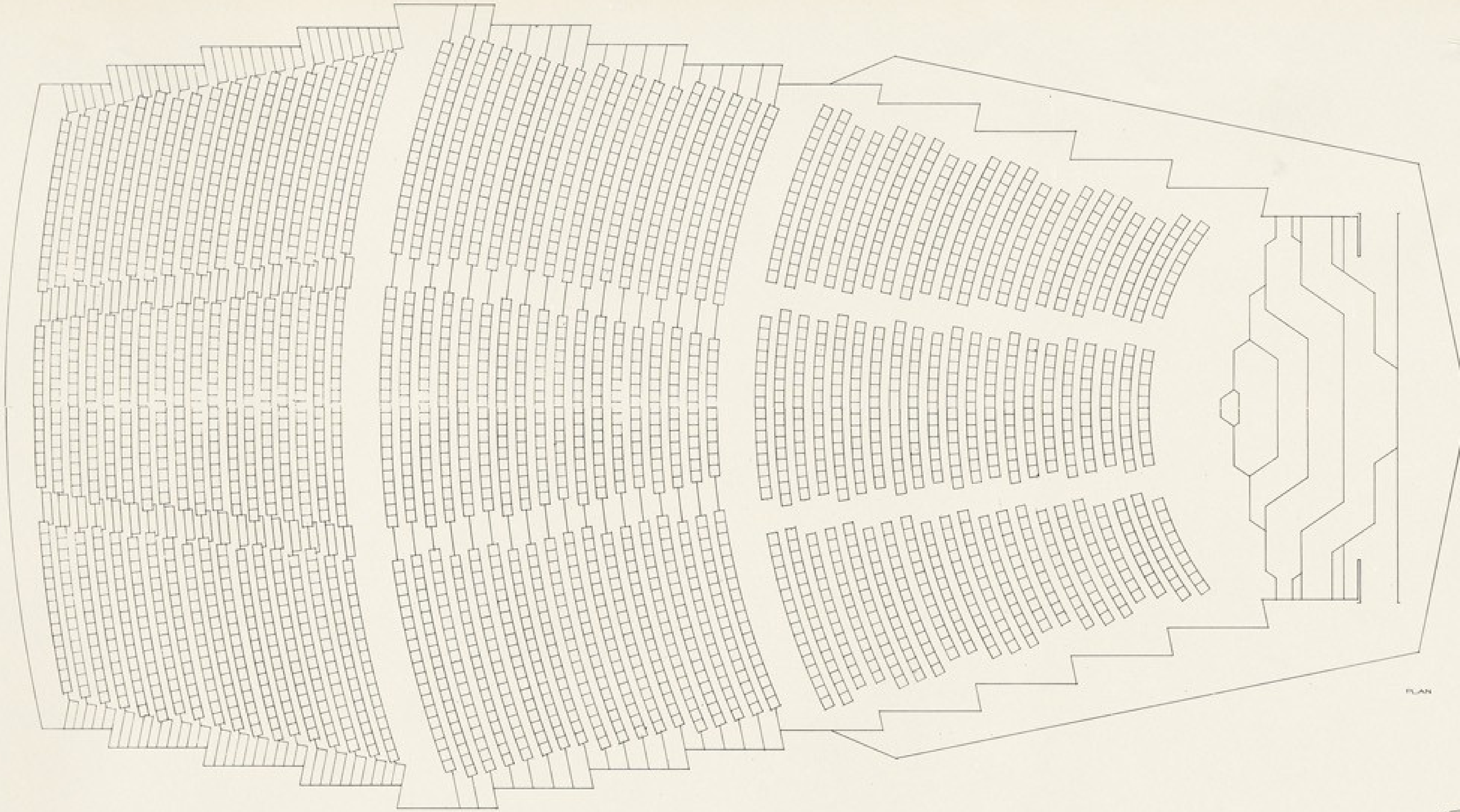
SECTION THROUGH STAGE TOWERS   SCALE 1/32" - 1'-0"



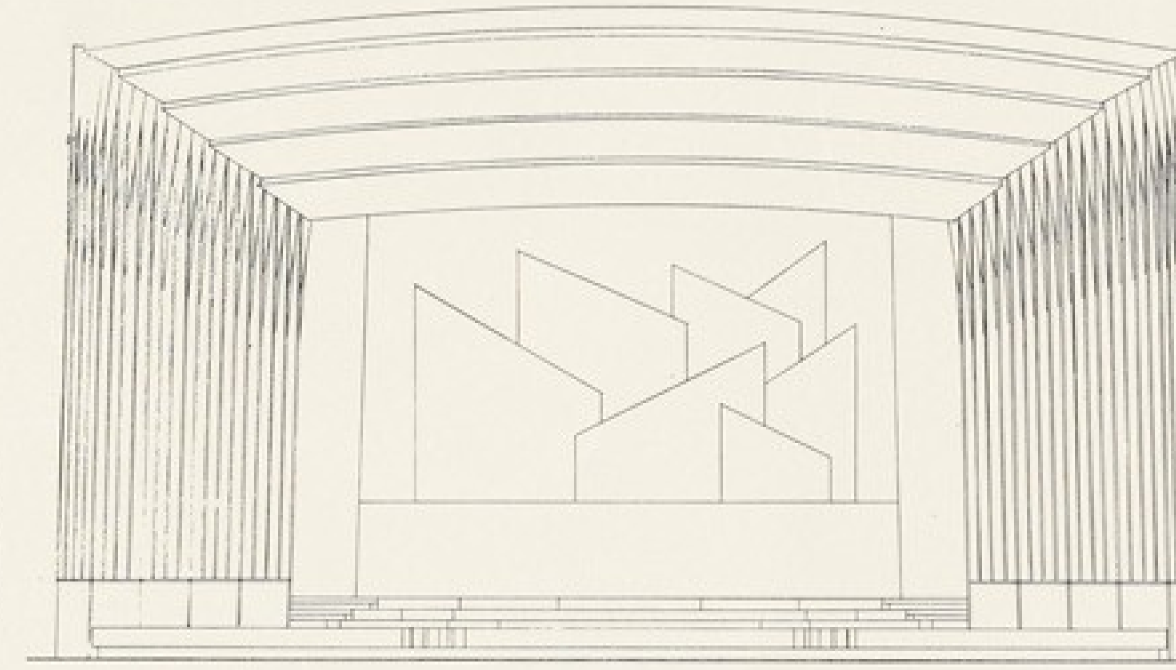
LONGITUDINAL SECTION THROUGH CENTRAL PASSAGE SCALE 1/32" = 1'-0"



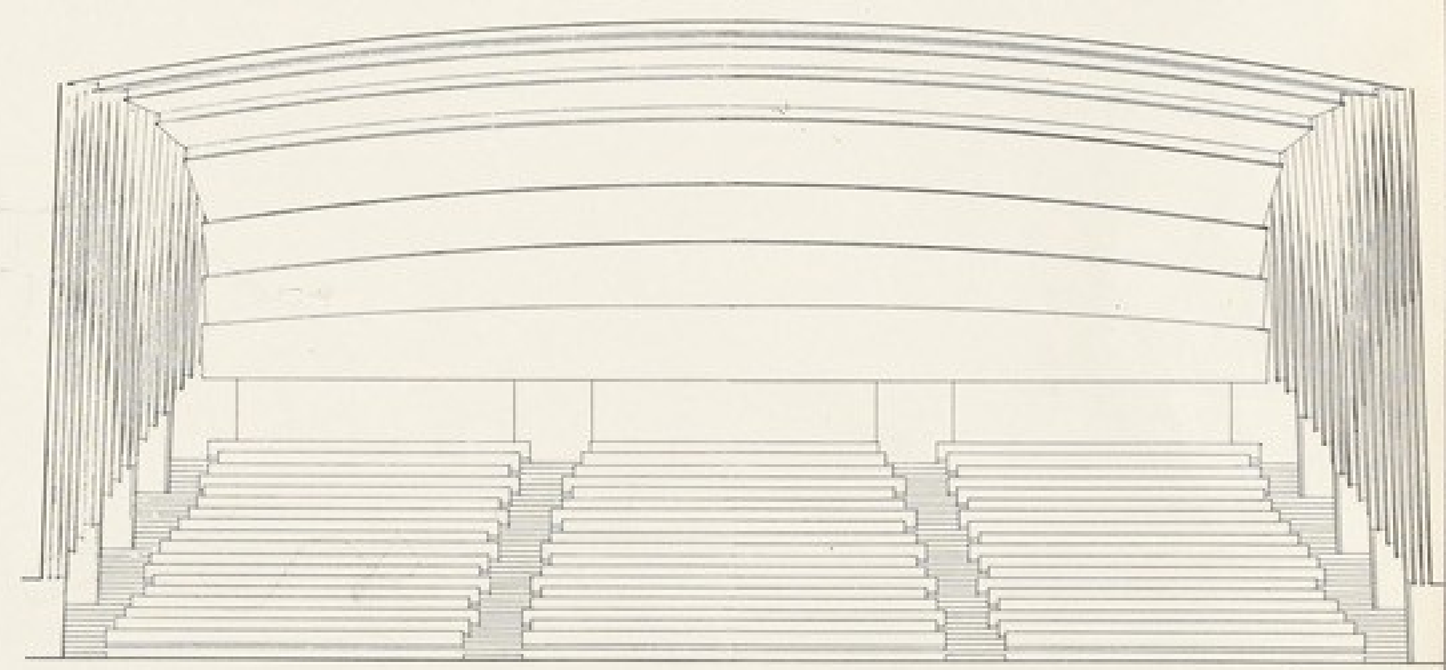
SECTION THROUGH CONCOURSE SCALE 1/32" : 1' - 0"



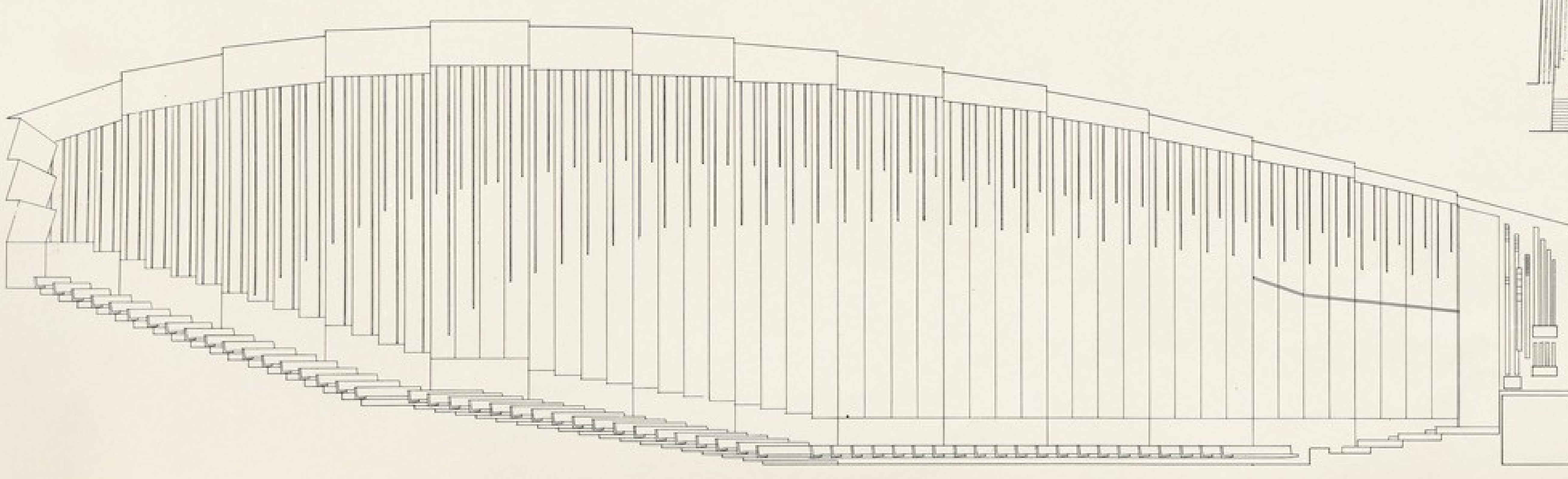
PLAN



SECTION TOWARDS CONCERT PODIUM

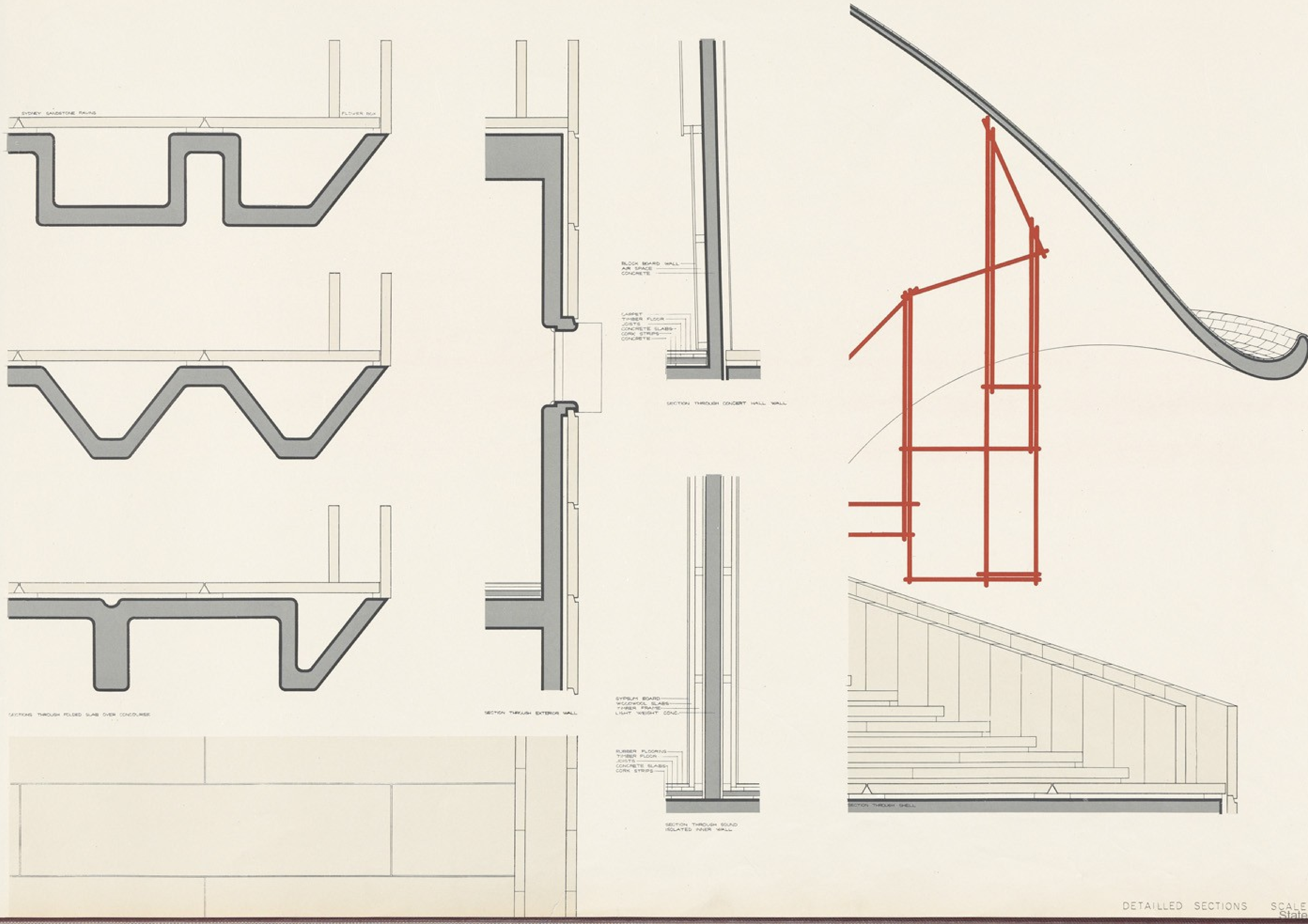


SECTION TOWARDS BACK-WAL



SECTION

INTERIOR OF MAJOR HALL – CONCERT HALL SCALE 1/16"-1'-0"



DETAILLED SECTIONS SCALE 1/2" = 1'-0"

S T R U C T U R E S

The whole of the sub-structure consists mainly of large horizontal slabs resting on concrete walls. The walls are those which are required for actual architectural reasons and very few extra columns have been provided. This has resulted in very large spans for the slabs. For architectural and structural reasons these very large floor spans have been designed as folded slabs, the folds being arranged in such a way that at mid-span where moments are positive (i.e. compression on top, tension at the bottom) most of the horizontal portion of the slab is situated at the top, whereas over the supports where the moments are negative (in case of continuity), most of the horizontal portion of the slab is at the bottom to take the compression. The transition from the one cross-section to the other is gradual, and in between the two extreme positions the slab is of through section.

This results in a comparatively light structure since the material is placed in a way which is most advantageous structurally. It also provides an interesting architectural effect seen from below.

The slabs are pre-stressed by cables of high tension wires. The folds of the slab form channels through which the rain-water which seeps in between the joints of the stone paving slabs can be led away. In different parts of the structure these large span slabs are supported in different ways because of intervening stair openings, and differences in the supporting walls etc. and these differences are directly reflected in the corrugations of the ceiling so that it is possible to see exactly where the positive or negative moments occur in each portion of the corrugated slab.

The super-structure consists partly of walls and ceilings to the Concert Halls, the shape of which is determined by acoustical considerations, and secondly by a series of large shells covering the whole of the buildings.

The structural design of the latter is obviously quite a problem and has only just been touched upon. The first task was to define the shape of the shells geometrically. This has been done, at least as far as the main shells are concerned.

Each of the main shells consists of two symmetrical halves meeting in a ridge in the vertical plane going through the longitudinal axis of the Hall. This ridge is part of a parabola. The two symmetrical surfaces meeting in this ridge are roughly triangular in shape and descend on each side to a point which forms a support for the shells. These surfaces are formed by a series of coaxial parabolas with a common axis in the line between the two supporting points at ground level. All these parabolas therefore meet at the point of support and at this point are perpendicular to the horizontal axis.

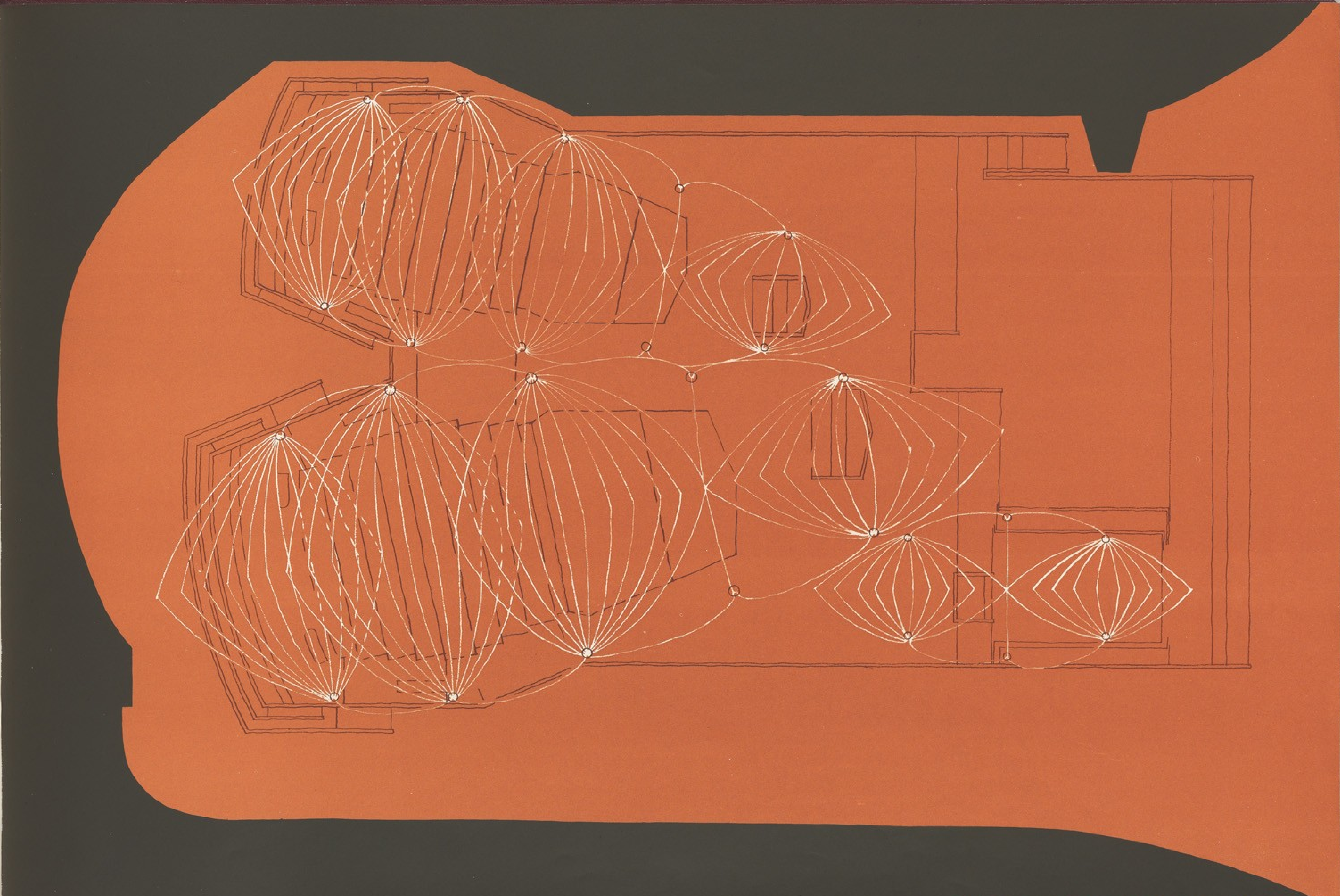
By thus defining the surfaces of the shells geometrically each point of the surfaces can be given spatial coordinates and a basis has been created for the calculation of the forces acting on the shells and the stresses created in the shells.

From a preliminary calculation it is obvious that the bending moments in the shells will be considerable owing to the heavy wind loads and it has been decided to provide the main shells on the inside with a series of ribs fanning out from the two supporting points and meeting in the ridge at the top.

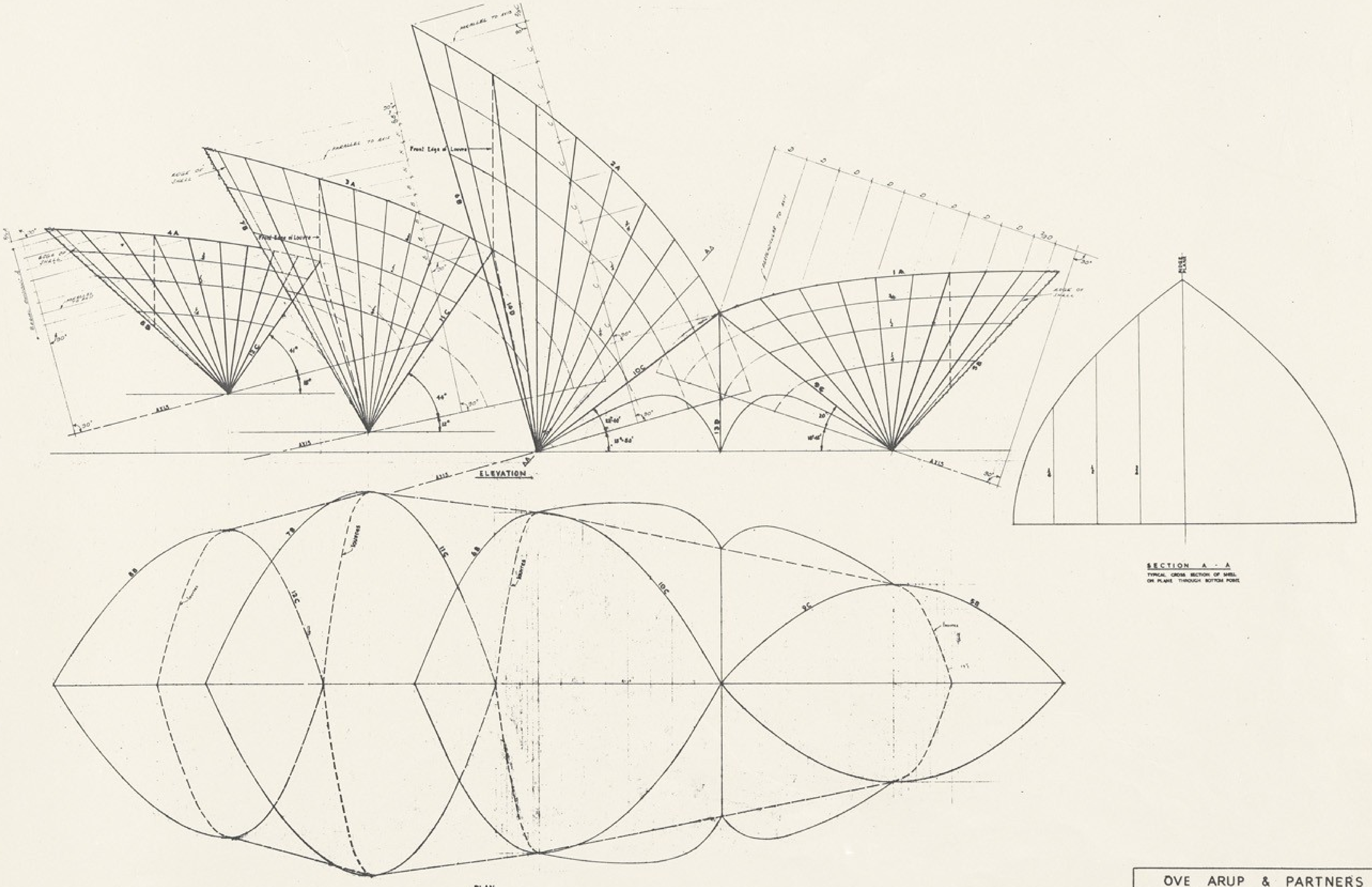
It has also been decided to make use of the louvre plane, i.e. the surface closing the opening of the shell, as a stiff membrane supporting the shell. It may even be necessary to connect the shells in some way to the internal structure of the Halls, but no decision has been reached yet. Extensive model tests will be required to arrive at a true distribution of stresses under varying loads.

Ove Arup

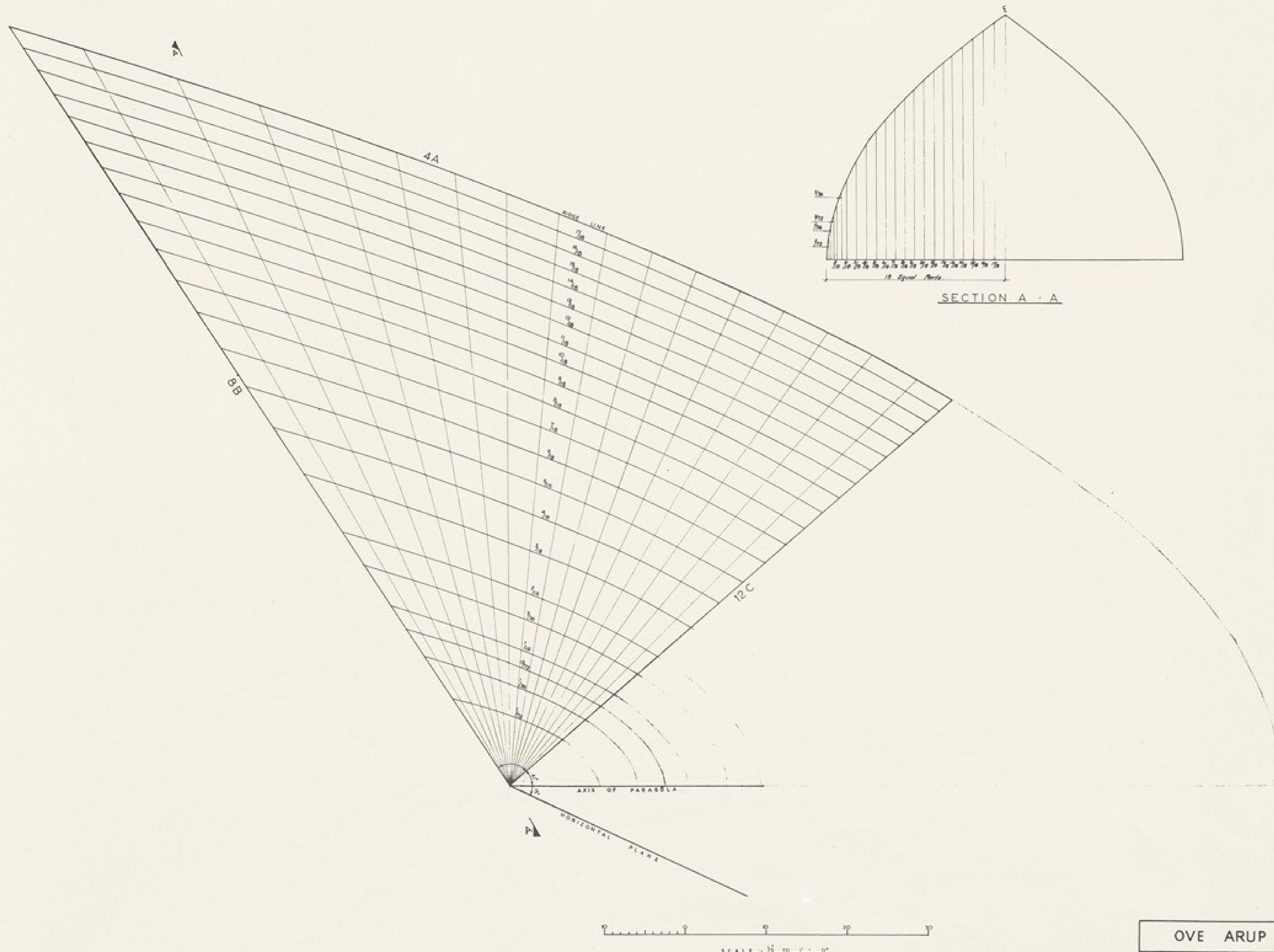
Ove Arup



PLAN OF PRINCIPAL CONSTRUCTION FEATURES   SCALE 1/32" = 1'-0"



OVE ARUP & PARTNERS			
LONDON: 8, FITZROY STREET, W.I.	DUBLIN: 19, MERRION SQUARE		
SYDNEY NATIONAL OPERA HOUSE			
PRELIMINARY LAYOUT OF SHELLS			
SCALES 1/16" to 1 foot	No 1112/SK2 B	ISSUE A B C D E	
DRAWN	TRACED		
PASSED	DATE		

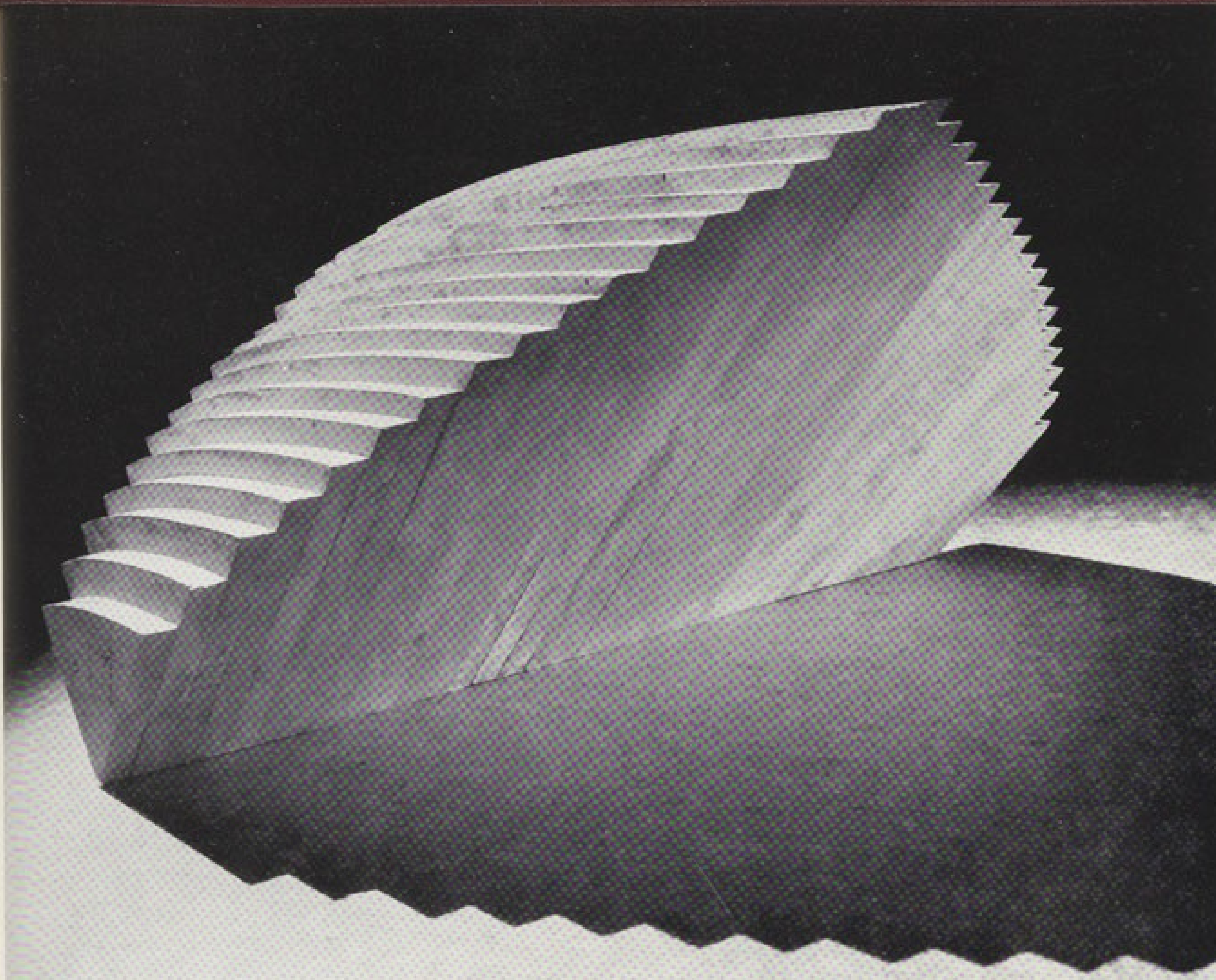


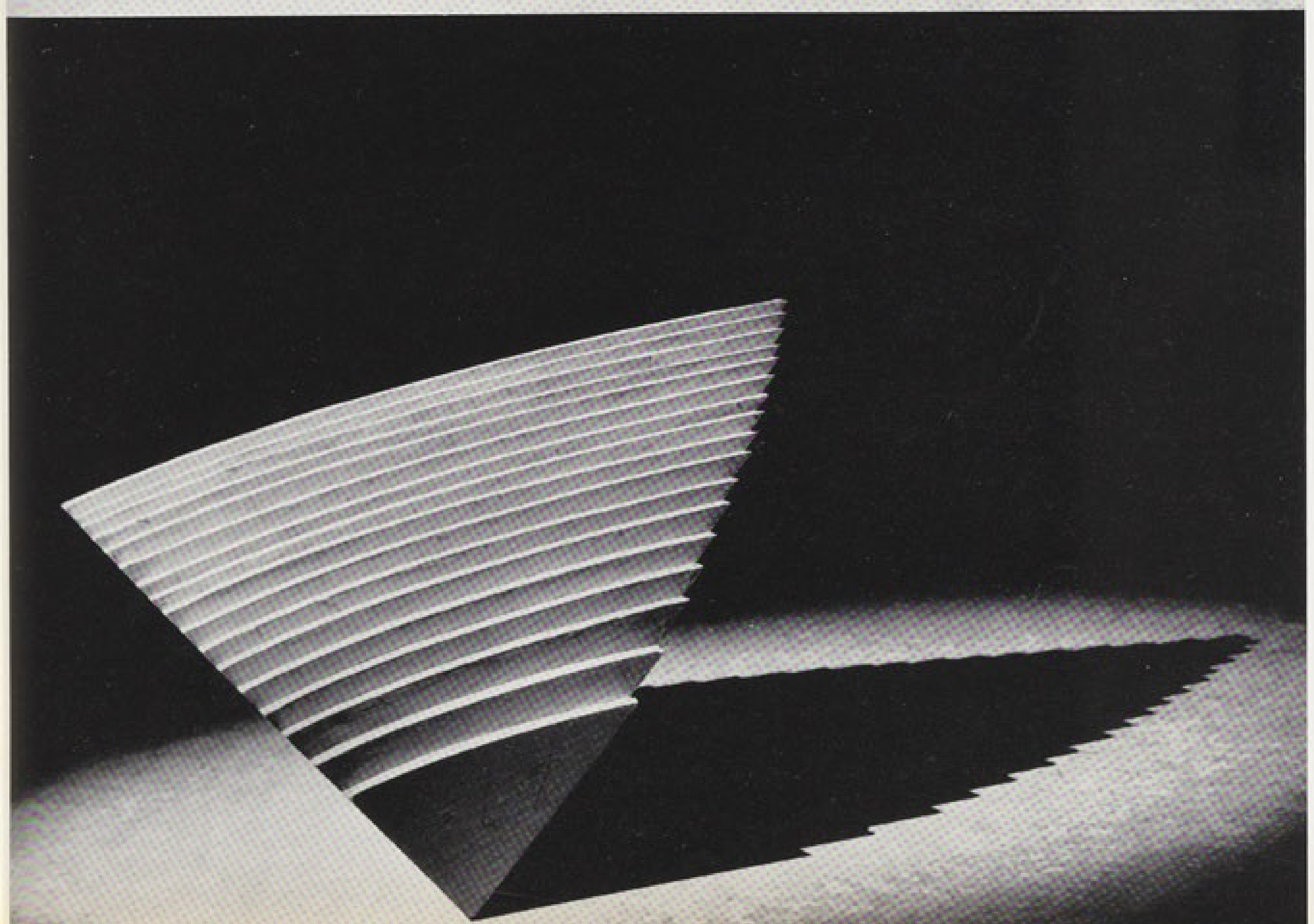
SECTION A · A

OVE ARUP & PARTNERS	
LONDON: 8, FITZROY STREET, W.1.	DUBLIN: 19, MERRION SQUARE

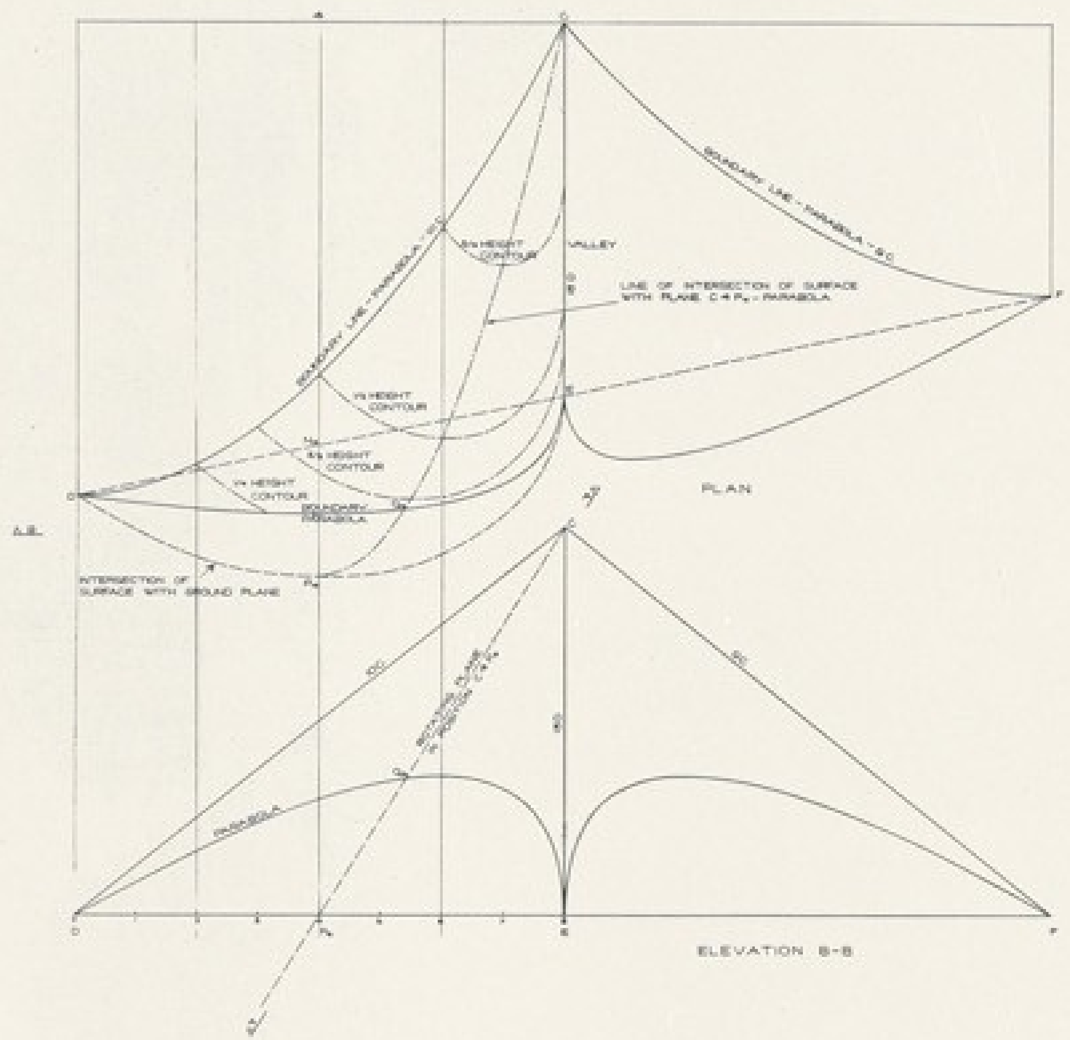
SYDNEY NATIONAL OPERA HOUSE
SHELL OVER BACK OF AUDITORIUM
MAIN THEATRE

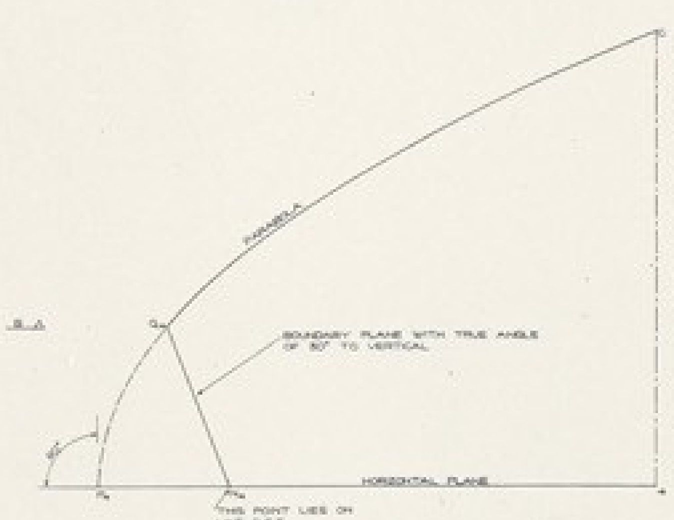
SCALES		Nº 1112/SK7	ISSUE	A	B	C	D	E
DRAWN	TRACED							
PASSED	DATE							





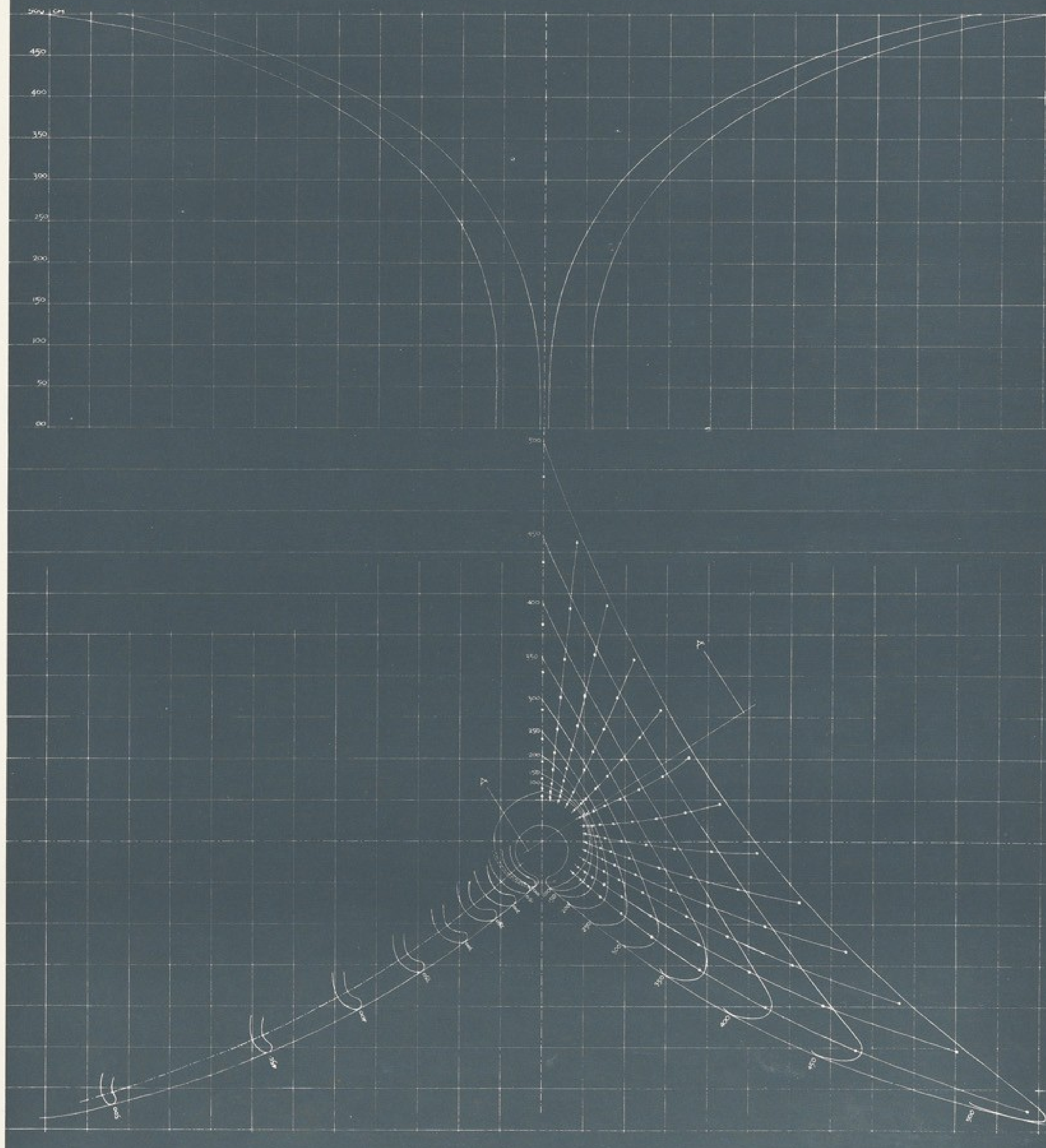
MODELS OF SHELLS



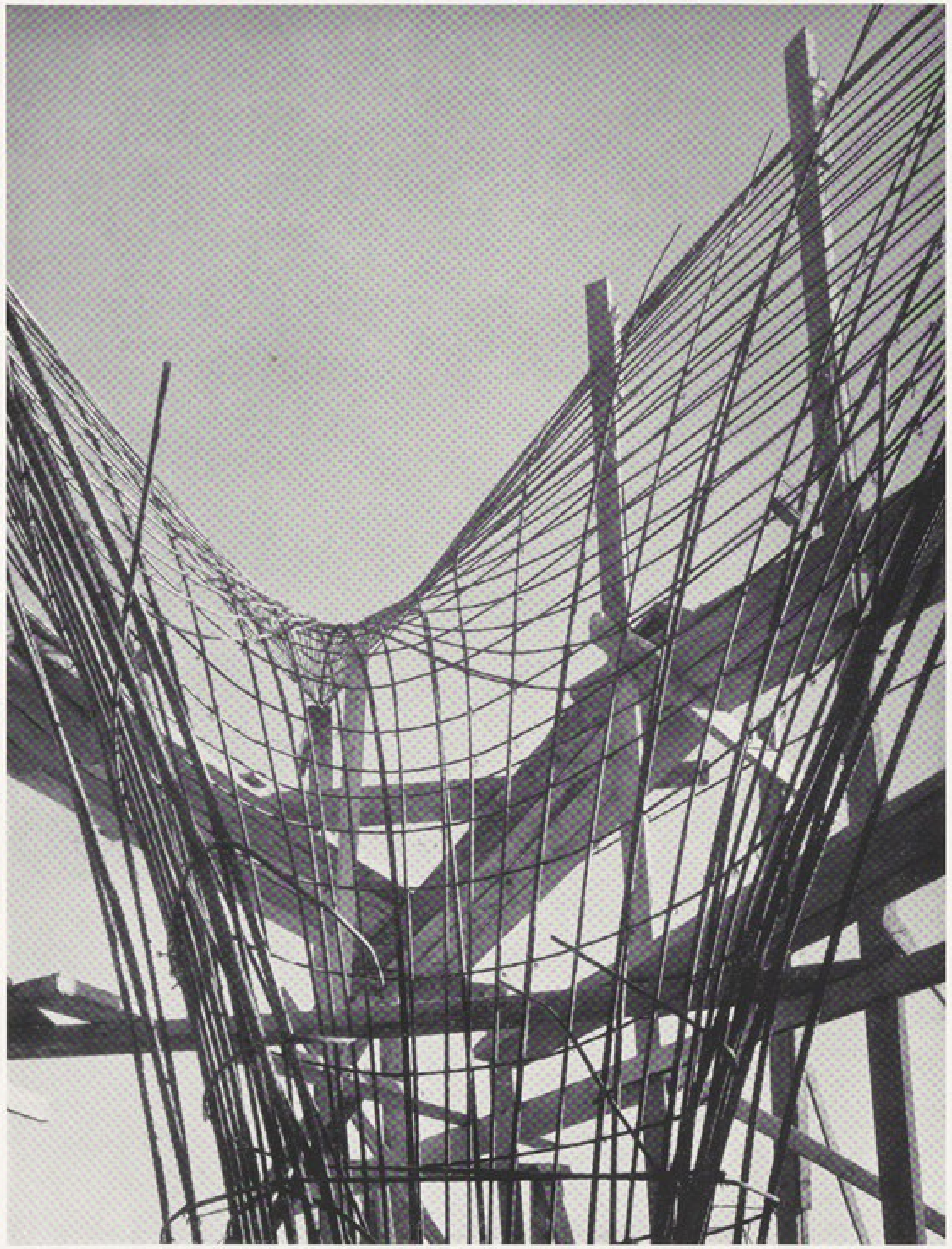


SECTION A-A'
TAKEN IN ROTATING PLANE IN POSITION C4P4

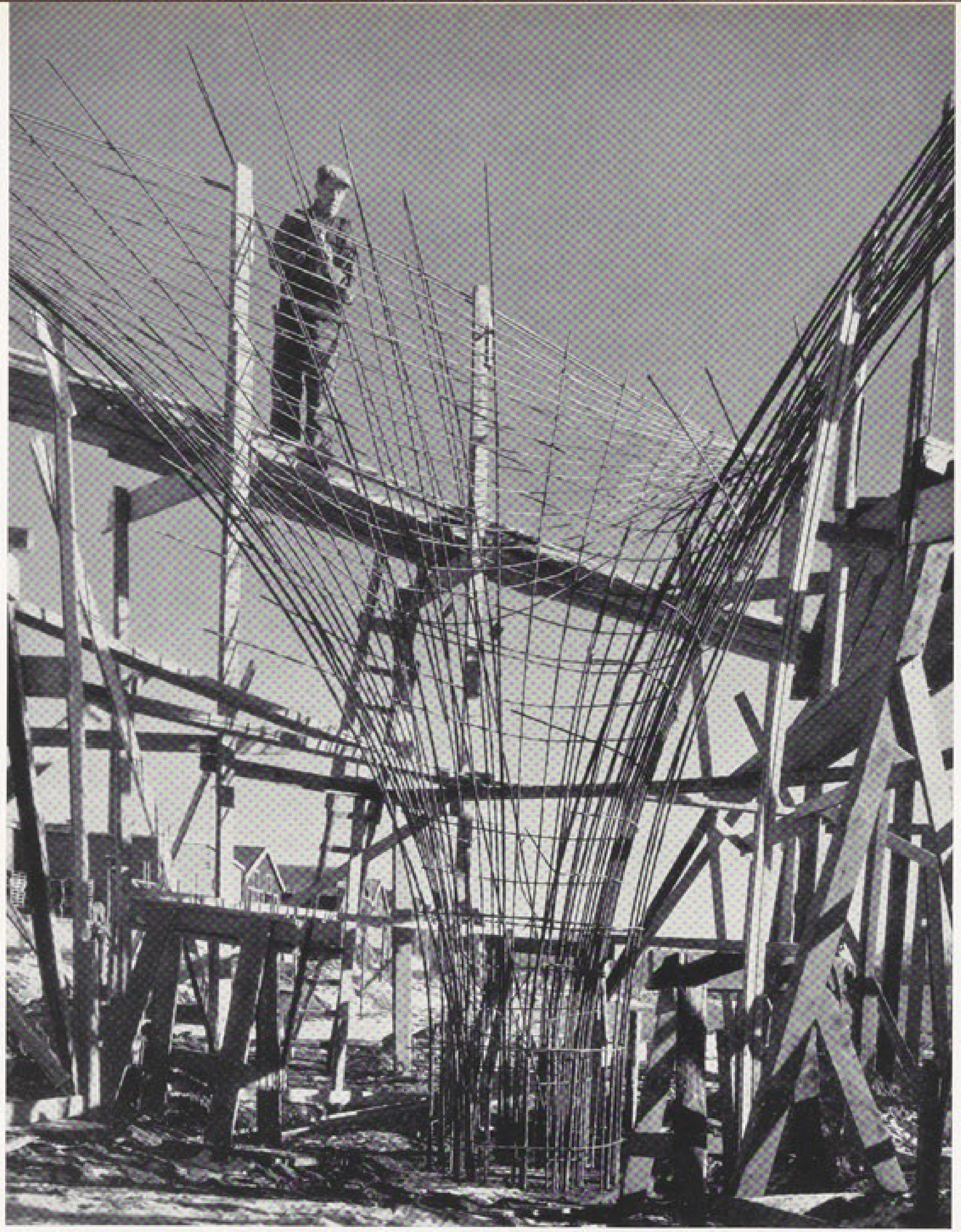
OVE ARUP & PARTNERS			
LONDON: 8, FITZROY STREET, W.1.	DUBLIN: 19, MERRION SQUARE		
SYDNEY NATIONAL OPERA HOUSE SCHEME FOR INTERSECTION SHELLS-			
SCALES DRAWN PASSED	TRACED DATE 10/5/61	Nº 1112/Sk.4	ISSUE A B C D E

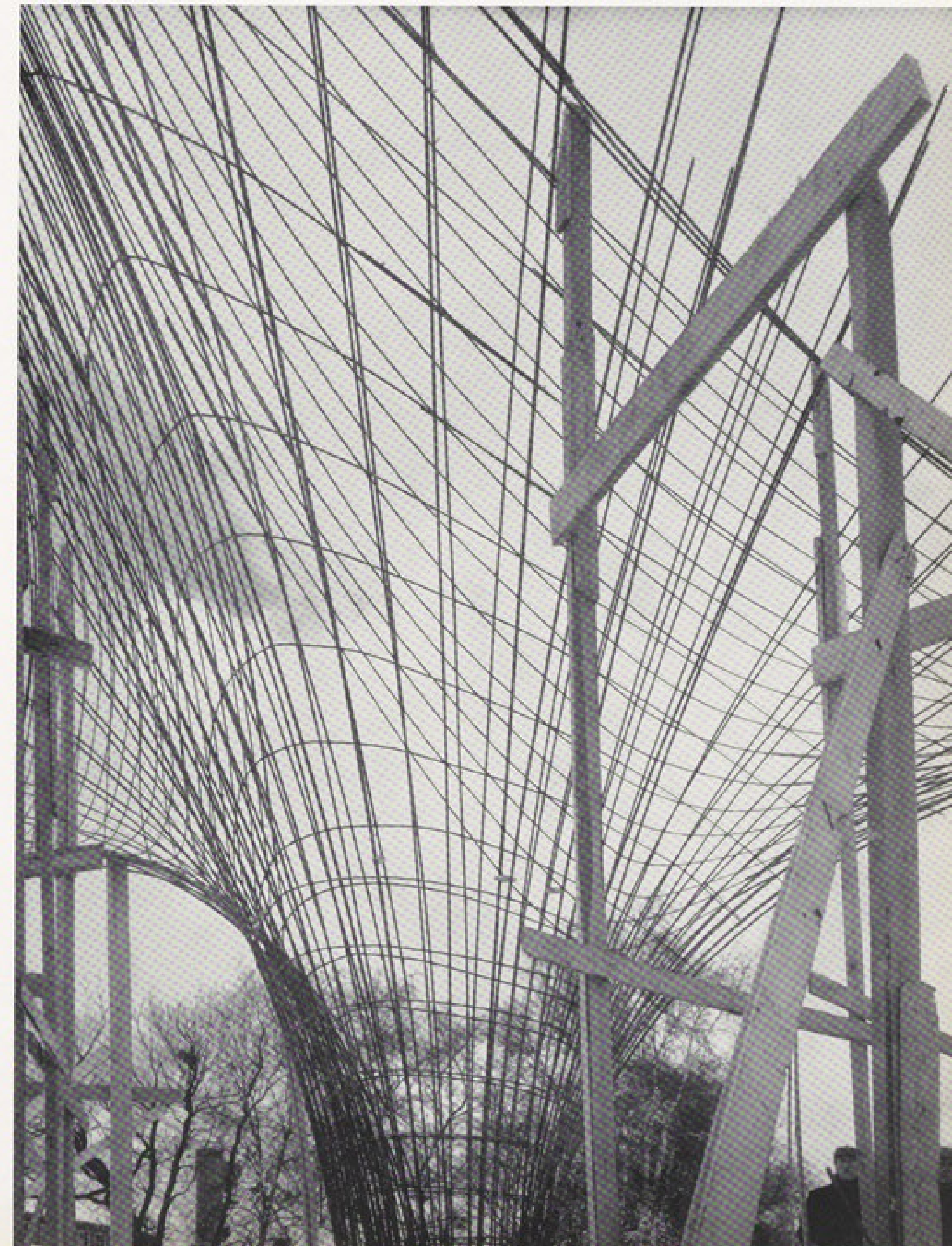


SCHEME FOR FULL SCALE MODEL

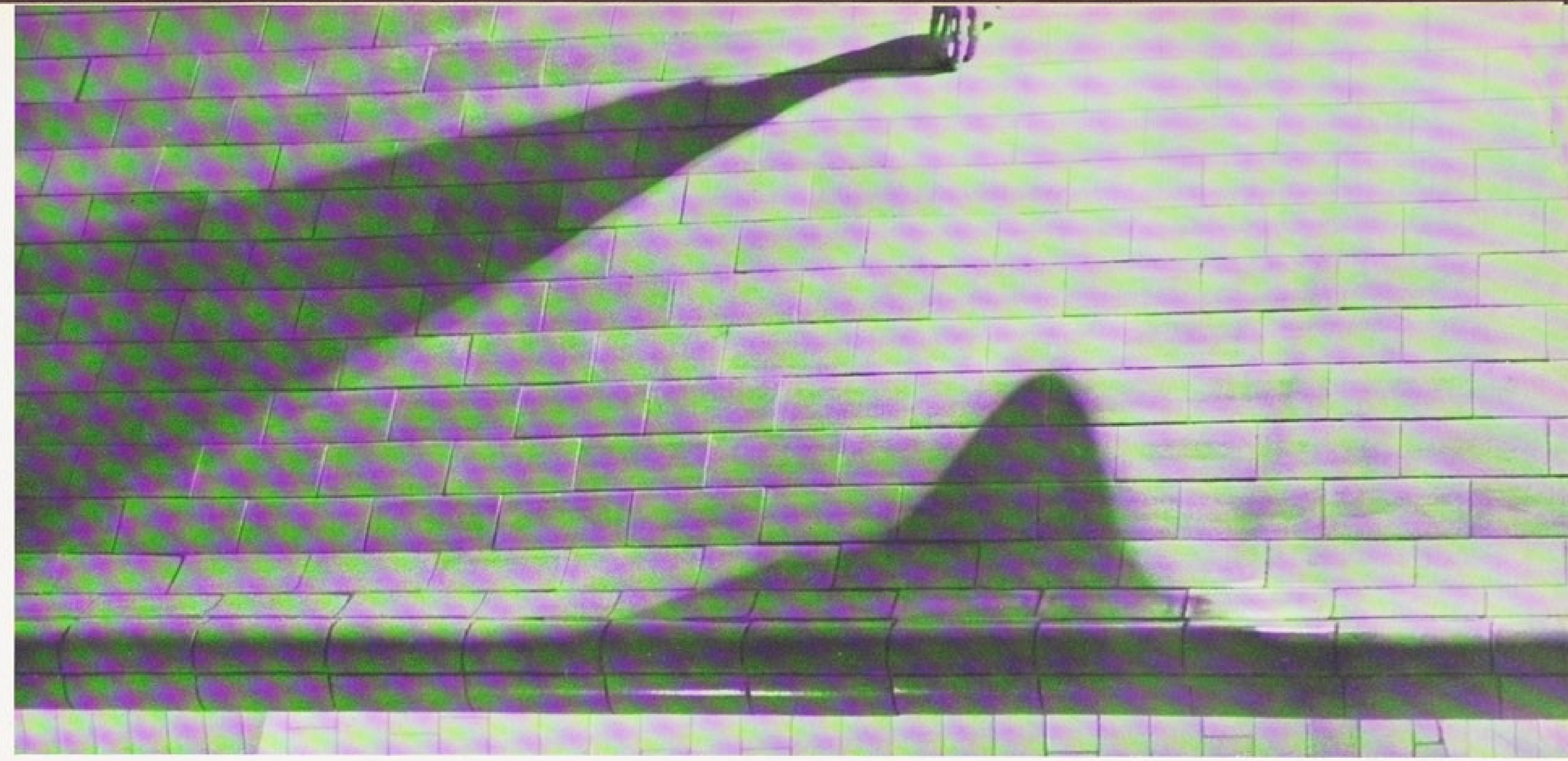


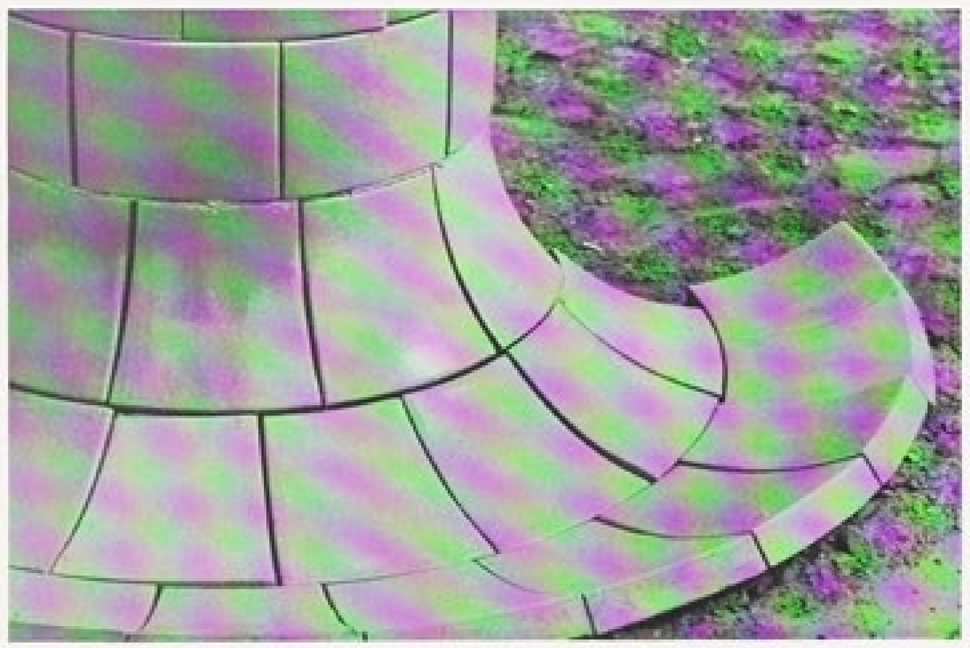
FIRST STAGE OF FULL-SCALE MODEL AT HÖGANÄS CLAYWORKS ALL PHOTOS: CARL E. ROSENBERG ARPS



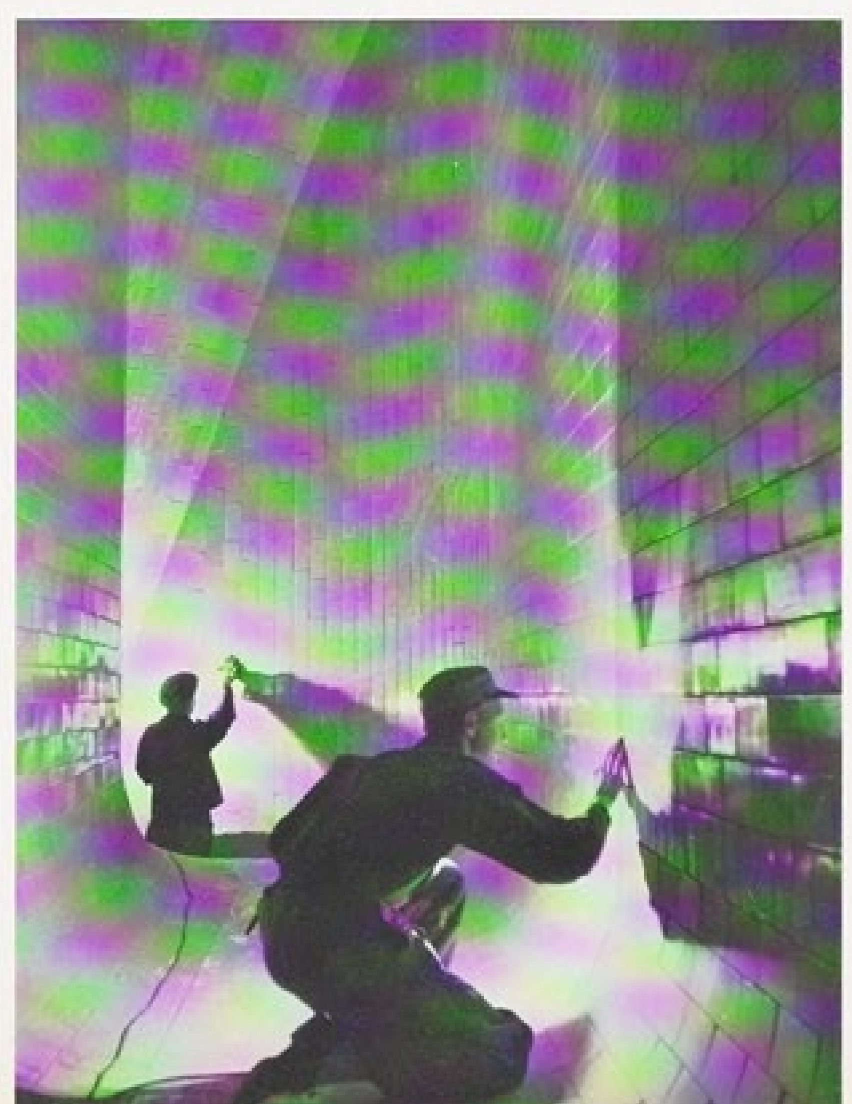


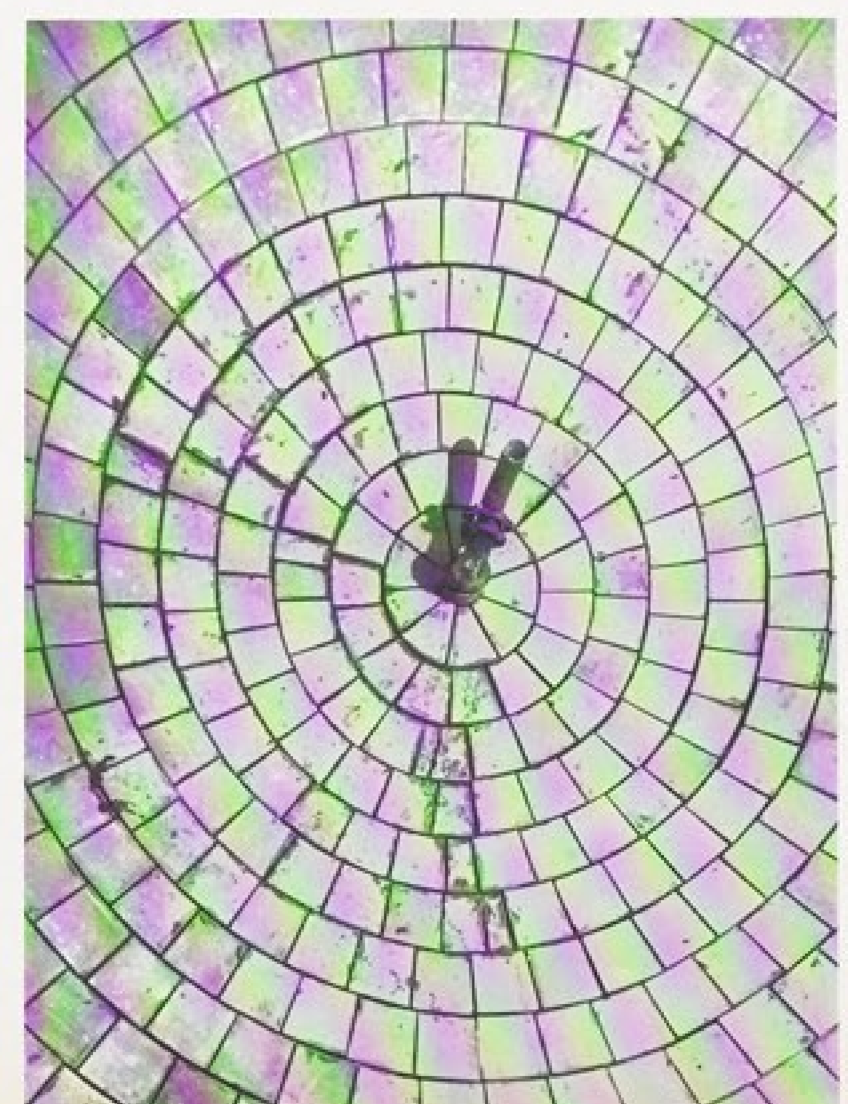
FIRST STAGE OF FULL-SCALE MODEL AT HÖGANÄS CLAYWORKS

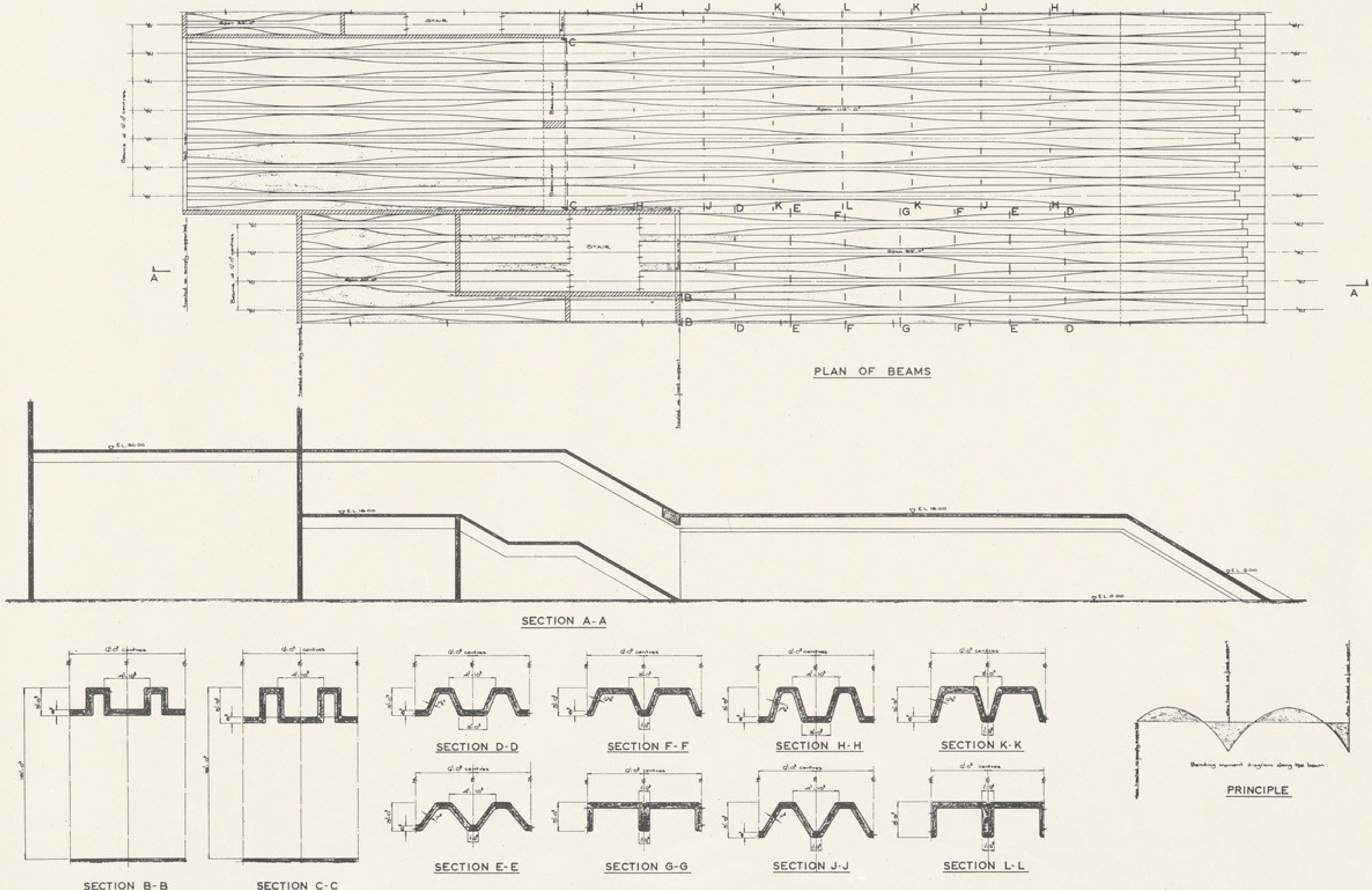




CERAMIC TILES USED ON CURVED SURFACES. HÖGANÄS CLAYWORKS







OVE ARUP & PARTNERS

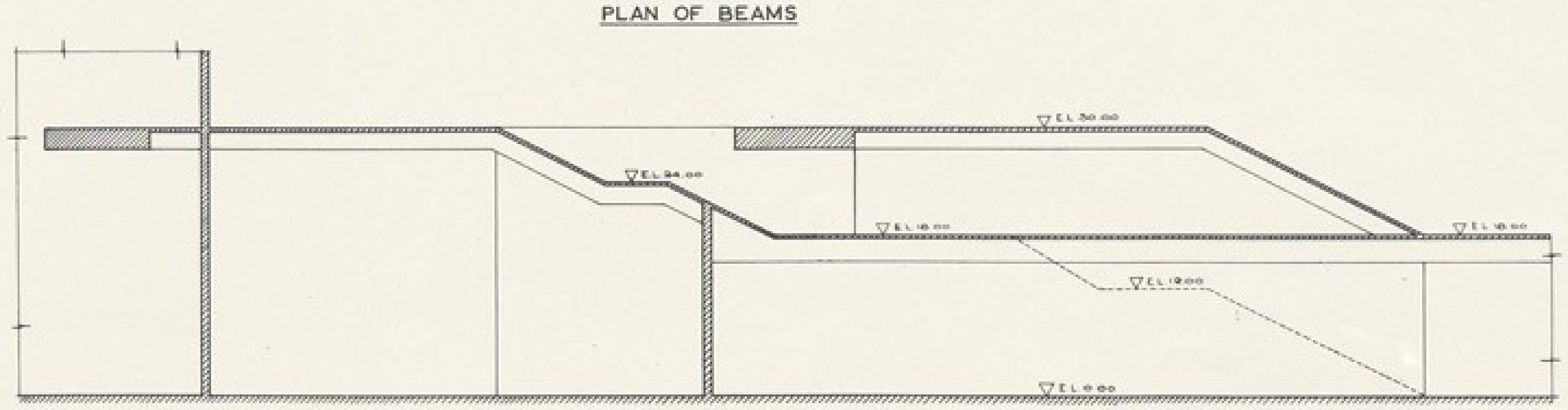
LONDON: 8, FITZROY STREET, W.1. | DUBLIN: 19, MERRION SQUARE

SYDNEY OPERA HOUSE
FIRST FLOOR BEAMS

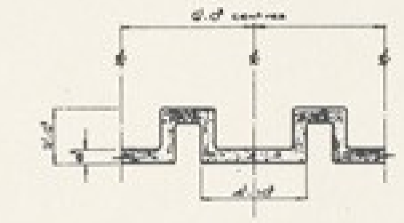
Nº 1112/Sk105

SCALES | DRAWN | TRACED | PASSED | DATE | ISSUE A B C D E

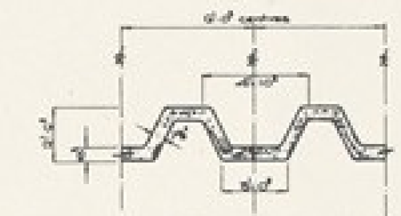
PLAN OF BEAMS



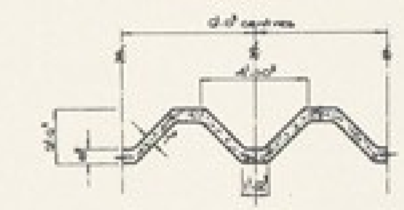
SECTION A-A



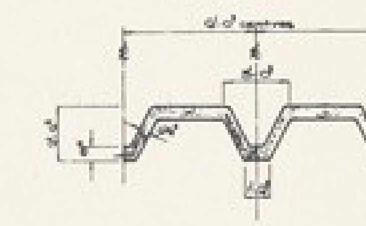
SECTION B-B



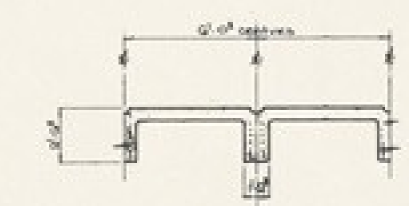
SECTION C-C



SECTION D-D



SECTION E-E



SECTION F-F

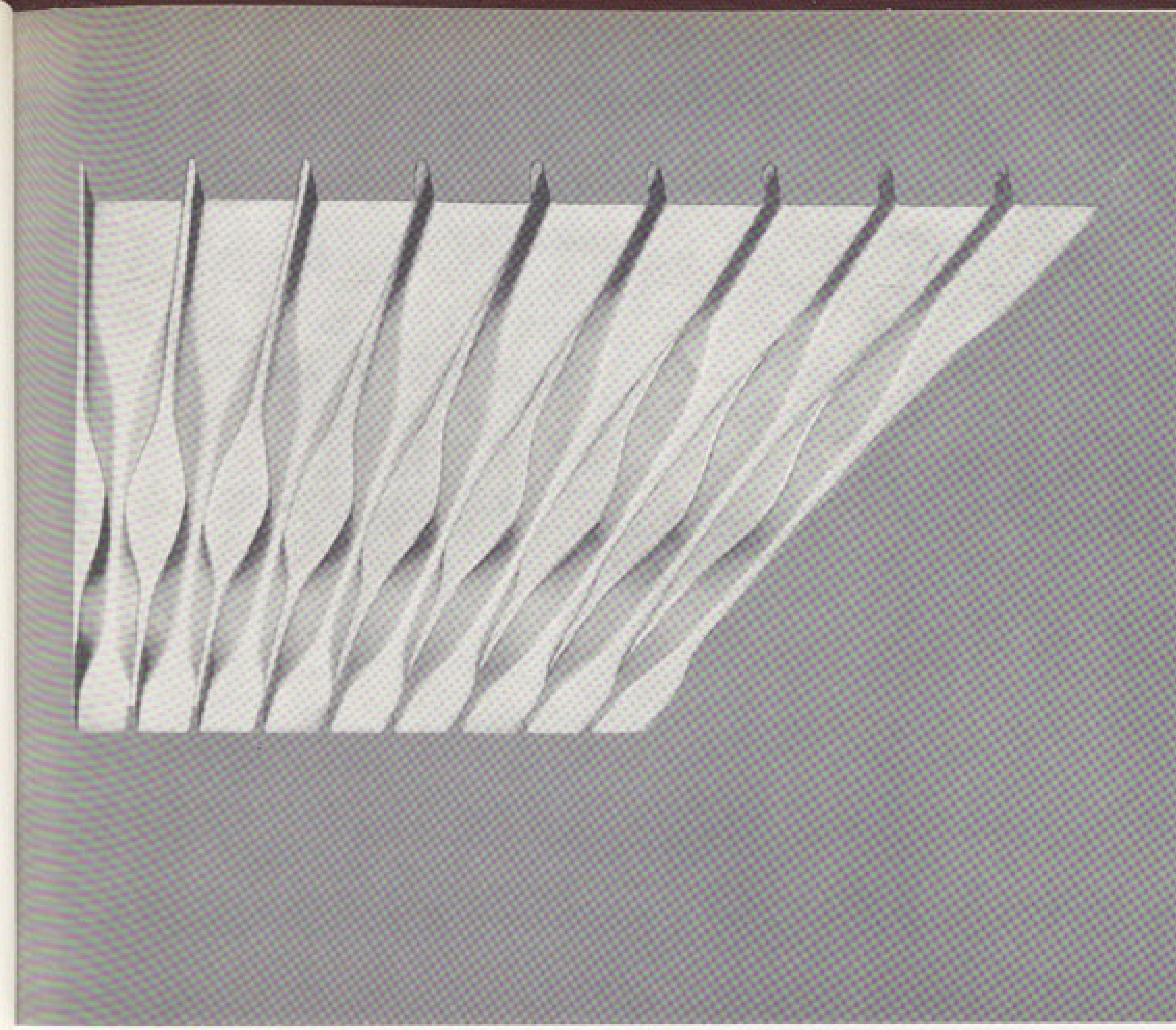
PRINCIPLE

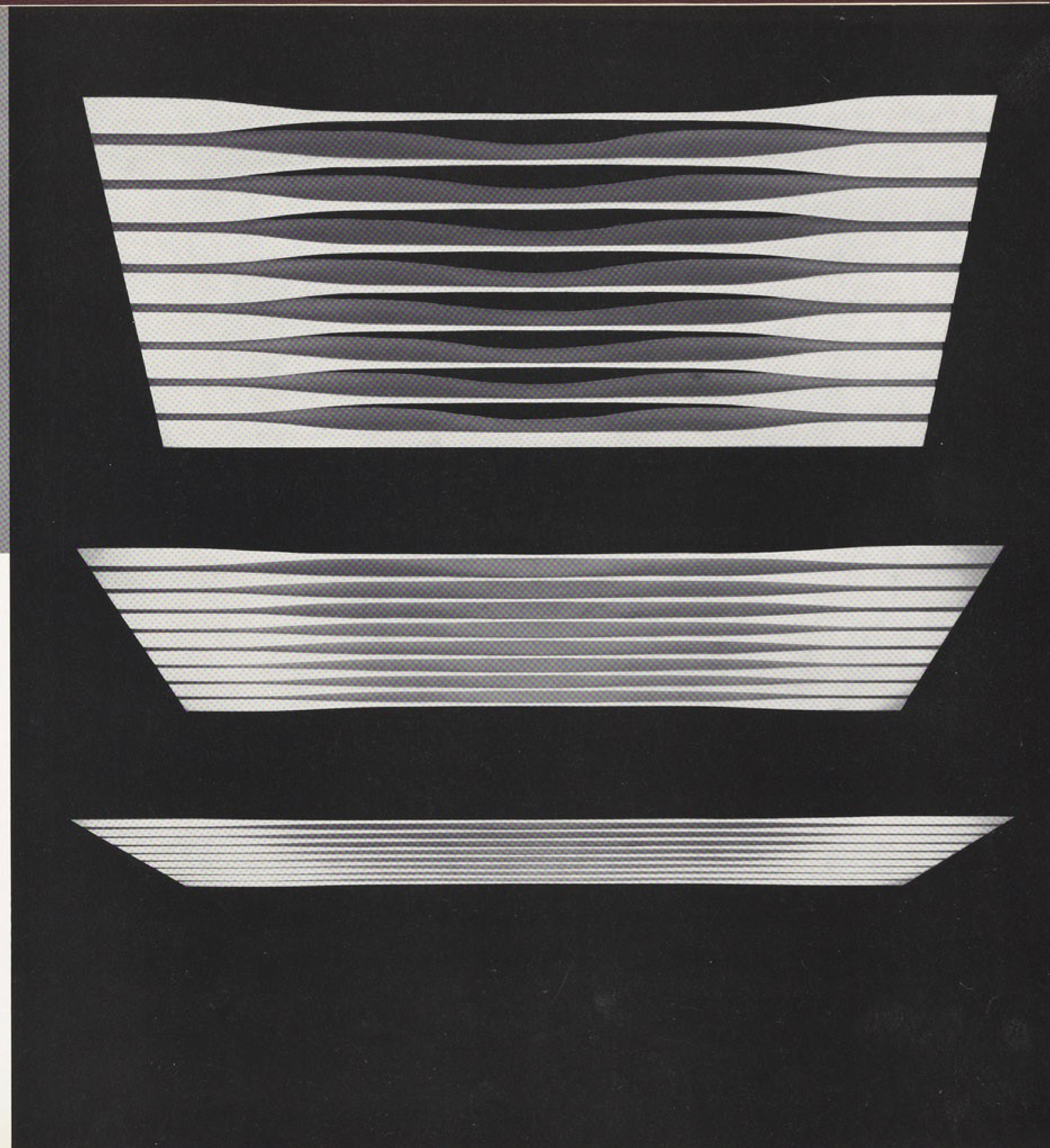
OVE ARUP & PARTNERS

LONDON: 8, FITZROY STREET, W.1. | DUBLIN: 19, MERRION SQUARE

SYDNEY OPERA HOUSE
SECOND FLOOR BEAMS

SCALES	DRAWN	TRACED	PASSED
DATE	Nº 1112/Sk106	ISSUE A B C D E	

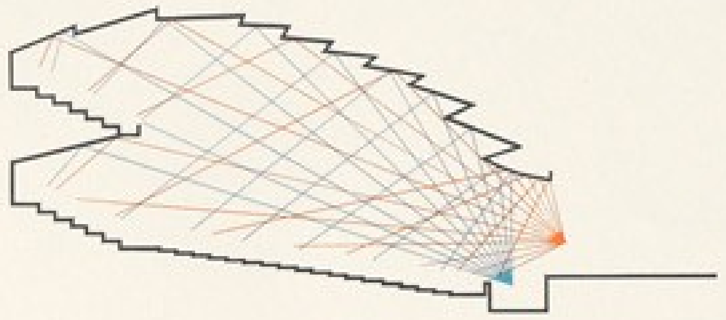




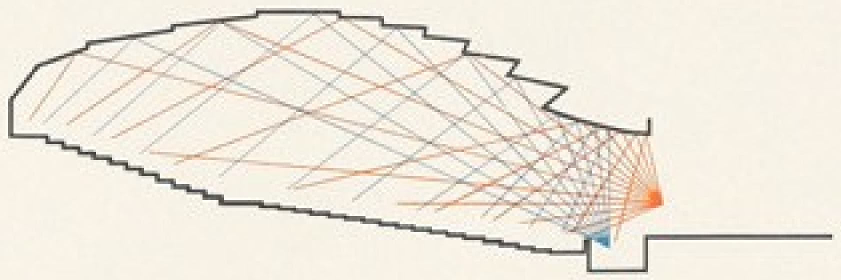
MODEL OF CONSTRUCTION OVER CONCOURSE

A C O U S T I C S

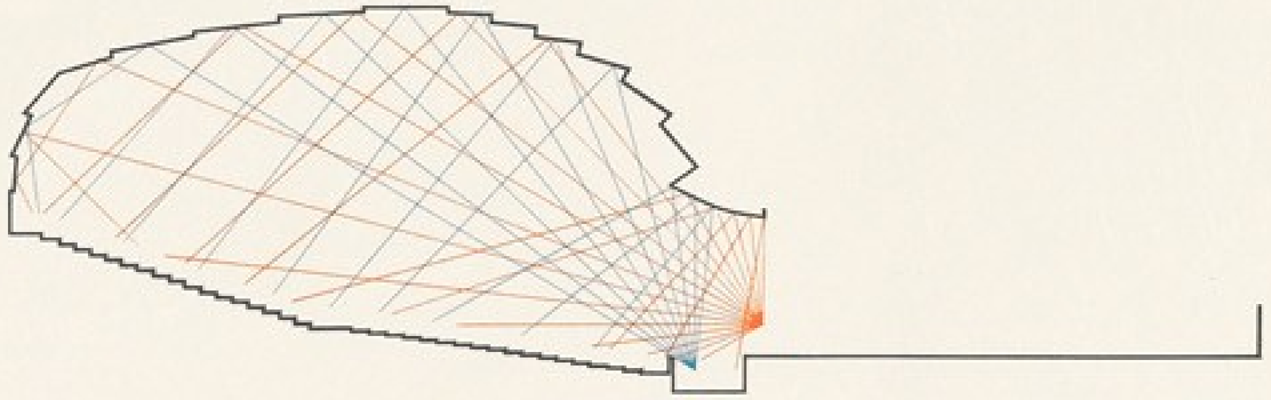
Content:



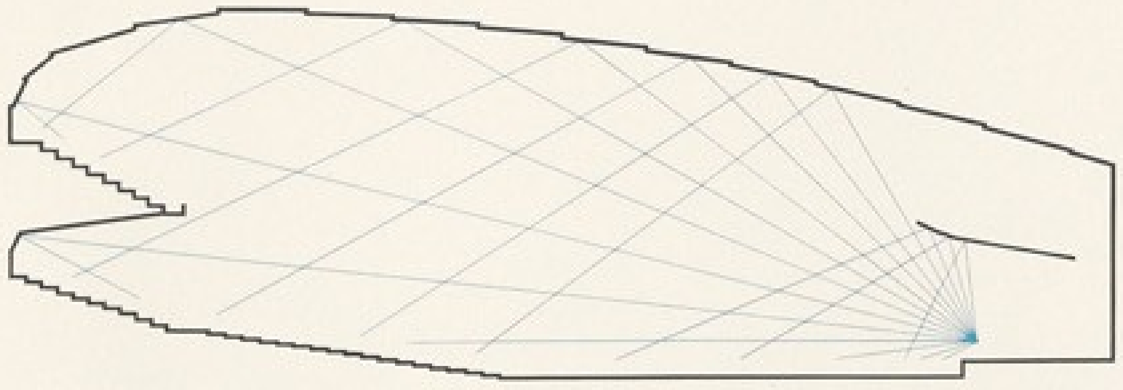
ALTERNATIVE THEATRE WITH BALCONY - MINOR HALL



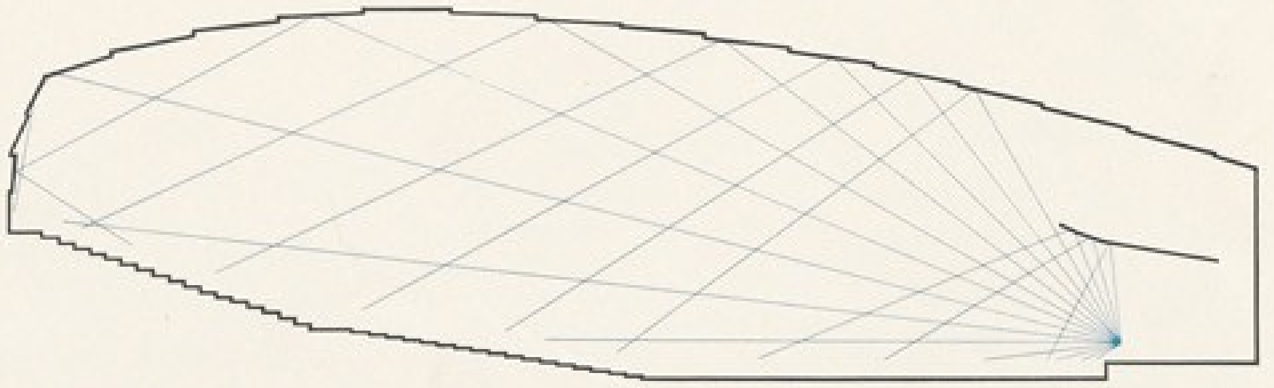
THEATRE MINOR HALL



CONCERT - MAJOR HALL



ALTERNATIVE CONCERT HALL WITH BALCONY - MAJOR HALL



CONCERT HALL - MAJOR HALL

SOUND REFLECTIONS IN HALLS   SCALE 1/32" = 1'-0"

§ 1. The Site and the outdoor Noise.

To the opinion of the author the site should be very favourable with regard to outdoor noise. Due to the considerable distance to traffic lanes there will only be little interference from city traffic noise. The main sources of open air noise will presumably be noise from the harbour traffic (engines, whistles, bells) and more important noise from airplanes. It is very urgent that a preliminary noise survey of the site should take place with as little delay as possible since the noise figures actually measured (or anticipated from measurements) have a direct bearing on the calculation of the sound insulation values which must be obtained from outer walls, shells, etc.. Especially wherever glass surfaces are part of the exterior boundaries it is quite obvious that the knowledge of expected maximum noise levels is indispensable.

§ 2. On the Principles of Large Hall Acoustics.

Although the acoustics of large halls are by no means a new branch of science and even though a solid foundation of quantitative calculation methods exists, there are still problems in this connection which must be solved in the individual cases more in accordance with general experience than by the use of mathematical formulae. We shall first consider the main criterium, i.e. the reverberation time (R.T.) and then proceed to the other principal features of large hall acoustics.

Reverberation Time. It is generally agreed upon that a definite range exists within which the R.T. of the completed hall should lay. Depending upon size and no. of seats a value within this range may beforehand be agreed upon and by appropriate calculations of the absorption of the seats, of the surfaces and of the air, this value may ultimately be obtained in the hall. The uncertainty of the calculation should be compensated by allowing a certain area of the walls (upperpart of side walls and back wall) to be fitted with easily interchangeable or alterable panels, thus securing the possibility of a final adjustment of the R.T.

It is, however, not only a question of obtaining a definite value of the R.T. at a single frequency, it is most important that the R.T. of the hall should be calculated and fixed for a large frequency range corresponding to the musical range of orchestral and organ music. It is commonly agreed that no very great variation of R.T. should be allowed within this range. A slight increase towards the low frequencies is permissible and a slight decrease towards the highest frequencies is unavoidable due to the increase of the sound absorption of the air at these frequencies. It is, in the opinion of the author, very important to keep this decrease of the R.T. towards the high frequencies within narrow limits and deliberately to counteract the influence of the sound absorption of the air by giving to most interior surfaces of the hall a finish, which will make them reflect as much of the sound energy of the high frequencies as possible.

The Sound Distribution in a large hall does not lend itself readily to exact calculation, but preliminary conclusions may be obtained from detailed studies of the geometrical aspects of the hall, especially from the main longitudinal section. In a more general way conclusions may be obtained by the use of model research. Actually it is not only the stationary sound distribution which may be studied in this way, but it is the transient behaviour of the hall to sound pulses. The "direct sound" from sound source to observer together with the first reflections, i.e. those which arrive within a time interval of 35 to 50 msec, after the arrival of the direct sound, are related to a certain acoustical quality, sometimes called "the definition", and which is important for the true reproduction of rapid passages in music.

The Sound Diffusion, too, is not a quantitative notion although certain attempts of defining it quantitatively have been tried. We know that a breaking-up of the surfaces in sections of the same order of magnitude as the different wavelengths of sound has an equalizing effect upon the sound field, which is important for the blending of musical sounds. No simple and convincing method of measuring sound diffusion exist so far, and there is also no generally recognized correlation between attempted definitions or measurements and the extent to which the surfaces are broken up, so that this feature, too, must be decided upon according to general experience.

The Overall Dimensions and the proportions between them have no exact relation to the acoustical quality of a hall, but it is agreed that too great deviations from "hármonic" proportions such as f.i. 2:3:5 (height: width: depth), shoud be avoided. Excessive width compared to depth is always dangerous because it makes efficient blending difficult especially in the front of the hall. Too little height compared to width and depth is also suspect, because it tends to reduce the reverberation of the hall unduly. Excessive depth should be avoided because too large a proportion of the audience gets too far from the sound source.

The General Shape of a large hall is a much disputed question.
No definite judgement in preference of either rectangular or fan shape ought to be pronounced, since there exist good halls (and bad halls) of both kinds. A too open fan shape, however, should be avoided, because the tendency to direct the sound towards the rear will be too great and thus will deprive the orchestra of too much sound and make it difficult for the musicians to hear each other playing.

On The Volume of a large hall it may be said, that there is a general agreement, that a certain relationship to the total number of seats should be maintained, an ideal being that the volume per seat is around 350 cbft (10 m^3), but deviations amounting to 30 % or more are in some cases permissible, if the effect upon the reverberation is matched by the control of the absorption.

Another Feature which, to the opinion of the author has been more or less neglected in many cases, but which according to his experience is quite important, is the transient behaviour of the stage and the immediate stage surroundings to sound pulses of different length. This behaviour is intimately connected with-how the musicians hear themselves and each other when playing, how the various groups hear each other and how the conductor hears the various groups. There is some indication from experiments, that this quality may have a numerical value, which may be expressed either by the rapidity with which a sound pulse "builts up" at the stage, or, even more exactly probably, by the "first slope" of the reverberation process as measured upon the stage. Actually, it shows, that in various halls the reverberation process from pulses, when registered at, or near the stage, has a tendency to be "double sloping", having an initial steep slope and continuing with a more flat slope which more or less exactly corresponds to the reverberation time as measured ordinarily. Theoretically this may be explained by considering the hall as actually consisting of two coupled enclosures, one being the stage and the immediate stage surroundings, the other being the seating area of the hall. It is obvious, that if too much of the sound energy stays at the stage (as f.i. when the stage is more or less closed off from the audience as in a theatre) there will be a deficiency in the performance of the hall, but it is also a matter of experience, that if too much of the sound energy is distributed towards the audience immediately, there will be a lack of response upon the stage itself, which gives difficulties for the musicians. Between these two extremes (corresponding to a very small coefficient of coupling and a very large one) there apparently must be an optimum, which it must be possible to decide upon quantitatively.

§ 3. Some Examples of Existing Large Halls and their Acoustic Data.

The following halls are mentioned:

a. Gothenburg Concert Hall
b. St. Andrews Hall, Glasgow
c. Usher Hall, Edinburgh
d. Royal Festival Hall, London
e. Concertgebouw, Amsterdam
f. Aalborghallen
g. Tivoli Concert Hall, Copenhagen.

This choice obviously is arbitrary; they are mostly halls of which the author has some personal experience (with the exception of (e)). They are all in the seating range of 1400 to 3400, the smallest being (a) and the largest (d). The table (1) below gives volume, number of seats, volume per seat and R.T.

Table 1.

year of completion	Hall	Volume cbft.	No. of seats	Vol.per seat cbft.	R.T. (mean) empty measured	R.T. (mean) with audience	calculated = c measured = m
1935	Gothenburg	420.000	1.371	308	1.8	1.6	c
1877	St.Andrews	570.000	2.700	211	2.6	1.8	m
1914	Usher Hall	550.000	2.750	200	2.4	1.5	m
1951	Royal Festival Hall	775.000	3.400	228	1.8	1.5	m
1887	Concertgebouw	730.000	2.275	322	2.8	2.2	?
1953	Aalborghallen	880.000	1.800	490	3.0	1.9	m
1955	Tivoli Concert Hall	450.000	1.780	253	2.2	1.3	m

a. Gothenburg Concert Hall.

The R.T. is in the proper range for the size of the hall, and the RT vs. frequency curve is fairly smooth and level till about 3000 cps (with the exception of a pronounced peak at 200 cps, which may cause some colourations to low frequency sounds).

The shape favours the sound reflections directed towards the audience. Measurements of the stationary sound level (due to a sound source with a static noise spectrum for higher frequencies) show that the level is about 5 db higher at the rear of the hall than at the stage for frequencies between 1500 and 7000 cps.

Diffusion is provided by the side walls but not by the ceiling.

b. St. Andrews Hall.

The R.T. is in the proper range for the size of the hall. The R.T. vs. frequency curve is slightly dropping off from 300 cps and upwards (from 2,0 sec. by 300 cps till 1,5 sec. by 4000 cps.).

The shape is rectangular and no projecting surfaces are applied. Measurements of the stationary sound level (from the sound source mentioned above) show, that the level at the rear of the hall, for frequencies around 1000 cps, is the same as at the stage, but at the higher frequencies the level drops off at the rear. (About 5 db by 5000 cps., and about 10 db by 8000 cps.).

Diffusion is provided by columns and by the deep recessing of the ceiling.

The stage and stage surroundings may provide a good "building up process" of the sound.

The volume per seat is 211 cbft., which is somewhat lower than the figures for most of the halls which have been built recently.

c. Usher Hall.

The R.T. is in the normal range, maybe a bit low when the hall has capacity audience.

The R.T. vs. frequency curve is dropping off from 140 cps and upwards (1,95 sec at 140 cps and 1,2 sec at 4000 cps.)

The shape is horseshoe like a theatre but with a large and nearly rectangular stage. Measurements of the stationary sound level (from noise source) show a dropping off from the stage to the rear of the hall of about 5 db and independent of frequency (in the range 1000 - 8000 cps.)

Diffusion is provided from the balconies, columns and from some recessing in the ceiling. The volume per seat is about the same as in St. Andrews.

The stage provides a good building-up process.

d. Royal Festival Hall.

The R.T. is somewhat below the normal range. The R.T. vs. frequency curve is about level in the range from 200 cps to 1000 cps and then drops off slightly (1,5 sec. at 1000 cps., 1,2 sec. at 4000 cps.).

The main shape is rectangular in plan, but the side walls are broken up by the boxes. The large canopy reflects the sound towards the orchestra and towards the rear of the hall. Measurements of the stationary sound level show that the level is dropping from the stage to the rear about 5 - 10 db especially at the highest frequencies (5 db at 1000 cps., 10 db at 8000 cps.). The dropping off of the level is less pronounced on the Grand Tier.

Diffusion is provided from the boxes and from the corrugated ceiling.

The volume per seat is rather low.

e. Concertgebouw.

The R.T. is in the proper range and rather high. Nothing is known about the R.T. vs. frequency curve.

The shape is rectangular and no projecting surfaces are applied.

Diffusion should be ample from cofferings etc. The volume per seat is 322 cbft. which is high for an old hall.

f. Aalborghallen.

The R.T. is in the proper range and rather high. The R.T. vs. frequency curve is level with a slight rise below 100 cps. and above 1000 cps. The curve is dropping off above 4000 cps.

The shape is rectangular with a large canopy over the stage. The ceiling is broken up and the reflections from the ceiling are directed towards the seats.

Diffusion is provided from the ceiling and from the broken-up side walls.

The volume per seat is 490 cbft. which is high.

g. The Tivoli Concert Hall.

The R.T. is rather low for the hall with a capacity audience. The R.T. vs. frequency curve is fairly uniform and level from 100 cps. to 5000 cps. with a slight rise at 3000 cps.

The shape of the hall is slightly diverging in the plan and with horizontal ceiling, which is broken up, so that the sound is reflected towards the audience. The sidewalls are also broken up in such a way that side-to-side reflections are possible for the higher frequencies.

Diffusion is provided from the broken-up ceiling, the broken-up side walls and the balcony.

Measurements of the stationary sound level show a dropping off of the sound level from the stage to the rear of about 3-5 db. The reduction is less at the highest frequencies (5 db at 2000 cps., 1 db at 8000 cps.).

The stage contracts towards the orchestra so that the building-up process of the sound on the stage is very rapid.

§ 4. The Major Hall of the National Opera House.

The main purposes are (1) symphony concerts with an audience of about 2800 and (2) grand opera with an audience of about 1800.

By placing the orchestra and some of the seats upon the floor of the theatre stage some practical and also acoustical advantages are secured. The acoustical advantages are (1) that a large volume and a correspondingly large volume per seat is obtained when the hall is used for symphony concerts, (2) that the seating area close to the orchestra is horizontal, so that the direct sound is propagated freely towards the rear of the hall (3) by screening off the upper part of the hall near the stage, the volume and correspondingly the volume per seat is lowered when the hall is used for grand opera, which requires less reverberation and more articulation than symphony concerts.

The R.T. is envisaged to be 1,8 to 2,0 sec. for symphony concerts and 1,6 to 1,8 sec. for grand opera.

The R.T. vs. frequency curve is calculated to be substantially flat maybe with a slight increase at the low frequencies and also a slight increase at frequencies around 2-3000 cps. (at least it is attempted to keep the R.T. from falling off in this region).

The upper part of the side walls and the back wall should be covered with panels, which can be changed in their absorption characteristic, so that they can be used for the tuning-in of the hall. An area of about 7000 sqft. is appropriate for this purpose.

The main shape of the hall is a "double fan" having the largest width and the largest seating area in the middle. The side walls are broken up in sections which have surfaces parallel to the longitudinal axis of the hall. This make side-to-side reflections possible in the high frequency range. In the medium frequency range the side walls will provide diffusion. The main shape of the ceiling with the two slopes approximate to a large extent a shape which gives a good sound distribution, but furthermore the ceiling is broken up in sections whose surfaces are inclined, so that the sound reflections are spaced equally over the audience. For low frequencies this shape will provide diffusion.

The volume is for symphony concerts app. 1.100.000 cbft. corresponding to a volume per seat of about 390 cbft. For grand opera the volume is reduced to app. 650.000 cbft. corresponding to a volume per seat of about 360 cbft.

The proportions of the concert hall are: (mean) height: (mean) width: length = 2:2,4:4,7, which is rather near to the harmonic proportions.

The curvature of the rows and the back wall is a bit too pronounced, the centre of curvature being at the back wall of the stage house. This must be corrected by appropriate corrugation of the back wall (sections with surfaces perpendicular to the main axis of symmetry) and of the steps between successive rows (same corrugation).

The stage for symphony concerts is approximately an enclosure with one wall missing, thus a rapid "building-up" process is ensured. The canopy may be moved vertically so that the stage volume may be adopted to the musical purpose.

The organ is placed on the back wall of the stage elevated about 10 ft. over the stage level and closed off when not in use.

The finish of the interior panelling (preferably wood) should be hard, smooth and polished, so that a maximum of high frequency reflection is obtained. Between the stage and the seating area a relatively large distance of free floor space (marble or polished wood) should be allowed, so that a good reflection of the sound from here is ensured.

The back wall is vertical but reflecting shields of wood direct the sound down towards the audience.

The side walls are practically vertical, their inward slope being less than 5 o/oo.

The curvature of the ceiling in the cross-section is only slight (curvature radius app. 360 ft.).

The proper shape of the orchestra pit for grand opera is analogous to the shape of the orchestra stage for symphony concerts i.e. a chamber with one boundary missing, in this case the ceiling. Appropriate measures to ensure reflections from the walls of the pit in all horizontal directions therefore are taken.

§ 5. The Minor Hall of the National Opera House.

The main purposes are (1) Dramatic performances and (2) Intimate Opera in both cases with an audience of about 1000 - 1100.

The R.T. in this case should not exceed the range of 1,3 to 1,6 sec because definition and articulation are very important for these purposes.

The R.T. vs. frequency curve should be substantially flat in the whole range of musical frequencies, and care should be taken to ensure only a slight falling off at the highest frequencies.

Areas of panels for tuning-in purpose should be provided for on the upper part of the side walls and on the back wall.

What has been said already about the sound distribution and diffusion of the Major Hall equally applies to this hall but with even more stress upon an equal spacing of the first reflections over the audience.

The volume is about 280.000 cbft. corresponding to a volume per seat of about 265 cbft., which is considerably lower than in the major hall. This is due to the smaller ceiling height appropriate for the purposes of this hall.

The proportions of the hall are: 2:6:7 (mean height: mean width: depth), which is appropriate for a typical theatre hall, where the stress is laid more upon definition than upon reverbaration.

The curvatore of the rows and of the back wall also in this case is somewhat more pronounced than would be permissible, but this is compensated by breaking the curved surfaces up in flat sections perpendicular to the main axis of the hall.

The orchestra pit is shaped so that first reflections for the musicians themselves are obtained.

For theatrical performances the orchestra lift may be placed level with the floor thus making it possible to have some extra rows in the hall.

The finish of the interior panelling (also in this hall preferably wood) should be hard, smooth and polished.

§ 6. A Program for the Model Research of both Halls.

The model research has the following definite purposes: (1) Controlling the sound distribution of a stationary sound field, (2) Controlling the reverberation process especially the first slope of the process in positions at or near the stage, (3) studying the "building-up" process of short sound pulses, (4) listening tests.

ad. 1. It is obvious that by measuring the distribution of a stationary sound field, minor corrections in unequal distribution may be corrected by adjusting the reflecting surfaces.

ad. 2. The shape of the stage and the immediate stage surroundings may be evaluated by measurements of the first slope of the reverberation process thereby making it possible to adjust the coupling between stage and audience area.

ad. 3. The minute study of the "building-up" process of short sound pulses make possible a further detailed study of the acoustical conditions at the stage. The influence of the height from stage floor to canopy may thus be investigated with the purpose of ensuring optimal conditions in the actual situation in the hall itself.

ad. 4. A tape recording of music reproduced in the model with a speed which is as much larger in proportion to the normal speed as the model is smaller than the hall and rerecorded from a microphone in the model, makes it possible, when the tape afterwards is played with normal speed on a loudspeaker, to get an impression of how music sounds in the hall.

A study of the similarity demands of the model shows, that it is not advisable to use a smaller scale than 1:10, the limiting factor being the increase in the sound absorption of the air at high frequencies. Special attention must be given to the application of suitable model loudspeakers and model microphones which should be able to reproduce frequencies up till at least 40.000 cps.

§ 7. The Sound Insulation of the Entire. Building against Outdoor Noise.

The sound insulation against outdoor noise must be decided upon according to the results of the noise survey (as mentioned in § 1) together with the permissible noise level in the halls. The criterion for permissible noise in a concert hall is roughly a level of 20 to 30 db. though somewhat higher values could be allowed at low frequencies.

At least two complete structural layers must be envisaged, one being the shells and the glass surfaces behind the shell opening, the other being the concrete walls of the halls. In case it is necessary the insulation figure of these walls may be increased by an appropriate additional layer of some kind of light building boards. Some gain in insulation also may be obtained by reducing the reverberation time of the space between shells and interior ceiling.

§ 8. The Sound Insulation of the Interior.

The two main halls must be very thoroughly insulated against noise from each other. This is accomplished by: (1) complete structural independence, (2) two complete structural layers between the two halls.

ad. 1. Vibrations and structure-borne sound are effectively damped, if the two structures not only are separated on all points above ground but also are founded upon separate foundations, so that the vibrations have to pass through the ground itself and thus will be reduced in strength.

ad. 2. The sound level in a concert hall may at least momentarily (by fortissimo) reach values of, say, 100 db. This indicates that the sound insulation of airborne sound by order of magnitude should be not less than 70 db.

To obtain such high figures of sound insulation, complete structural independence as mentioned above, but also with regard to all piping, wiring, ducts etc. is essential. The two concrete walls and roofs of the halls then should provide the necessary two layers, whose insulation figures may be increased by additional layers of building board.

The little theatre is a building whose structure also is completely independent of the structure of the minor hall and which has its own roof below the concrete floor of the hall.

Due to the more isolated position of the chamber music studio, it is not necessary to build this studio up as a complete independent unit, but care should be taken that the two sections of the studio, which occasionally shall be divided by a movable partition, shall be thoroughly insulated from each other.

The several rehearsal rooms for conductors, soloists, musicians, etc. must be very well insulated from each other by using concrete floors riding on cork bricks and having walls and ceilings built upon these floors.

Noise from all technical services such as ventilating fans, lifts, water pipes etc. must be carefully damped by suitable insulation measures.

The noise level in the major and minor halls due to ventilation must not exceed a figure of 20 - 25 db.

§ 9. Acoustics of the little Theatre and the Several Smaller Rooms.

The R.T. of the little theatre preferably should be around 1 sec. and the frequency curve should be flat. From an aesthetic point of view a large ceiling height is wanted and therefore a heavy acoustical treatment of ceiling and upper walls must be envisaged.

The chamber music studio also requires an R.T. of about 1 sec. and a flat frequency curve. It ought to have some diffusing elements both upon walls and upon the ceiling.

The rehearsal rooms require values of R.T. in the range between 0.5 to 0.8 sec. according to their respective size and use. This may be obtained by appropriate acoustical treatment of ceilings and walls. Some diffusing elements also ought to be applied.

§ 10. The Sound Damping of Foyers, Stages, etc.

For acoustical convenience a great deal of all the rooms in the Opera House should be treated acoustically. This especially applies to the large foyer, restaurants, corridors etc., but also to restaurant kitchens and other larger service rooms.

A sound damping of the stage towers may be useful especially if they are only occasionally used for theatre decorations.

§ 11. The Facilities for Sound Amplification.

A sound amplification system for the entire building must be regarded as indispensable. A thorough planning of this system should be part of the whole project. Some of the features for such a system will be exposed in the following.

Major Hall.

For symphony concerts no sound amplification should be allowed. Only for pure entertainment concerts with microphone singers is sound amplification needed in the major hall. In a large hall like this, it may be necessary to use the delayed speech system, which in recent years have been introduced in several places, and which, when properly installed, is very successful in giving a natural sounding reinforcement of the human voice. In fact the impression from a correct system is, that only the speaker or singer himself is producing audible sound.

For use in operas it may be necessary to have a sound system upon the stage which sends out sound effects towards the audience.

Minor Hall.

A sound system for microphone talkers and singers should be planned but no delay system should be necessary in a hall of this size.

Another sound system for use during theatrical performances is necessary.

Overall System.

For communicating messages to the public, for emergency calls etc., an overall loudspeaker system in all public areas and also in all service areas should be planned. A central booth where all amplifiers, gramophones, tape-recorders, wireless receivers etc. are installed should preferably be placed close to the major hall. Probably it will prove convenient to have individual booths for all the halls.

§ 12. Conclusions.

A noise survey of the site should be undertaken with as little delay as possible, because noise figures have influence upon the calculation of the sound insulation of outer walls, shells, glass partitions etc..

It is emphasized that a model research of major and minor hall is particularly valuable for investigating sound distribution, reverberation process (first slope) and the "building-up-process" of sound pulses.

Complete structural independence of the buildings of major and minor hall and of all interconnecting piping, wiring, ducts etc. is a condition, which should be fulfilled to ensure proper sound insulation between the two halls. Also the little theatre should have separate foundations, walls and roof.

Noise from all technical services should not exceed a background noise level of more than 20-25 db in any of the halls.

A sound amplification system for the entire building is indispensable and a thorough planning of this system should be part of the whole project.

Vilh. Jordan

Vilh.Jordan

M E C H A N I C A L   S E R V I C E S

It is proposed to provide heating and full air conditioning throughout the building.

In the layout and detailed design of all plant and ducts emphasis will be made on noise abatement from mechanical apparatus and elimination of fire hazards, as well as sound transmission from space to space. Furthermore, the wind conditions particular to the site and their reaction on the internal pressures will receive careful consideration.

A tentative layout of plant rooms is shown diagrammatically on the plan of the basement.

The fresh air intake is placed in a pit as remote from the building as is practically possible. The inlet to the fresh air duct is covered with a vertical wire mesh to eliminate insect pests.

The fresh air (blue) passes through inlet dampers into the mixing chamber, where recirculated air is added. The inlet fans (five are shown) then draw the air through the oilfilter banks, cooling batteries, heating batteries and, if required air washers, into the inlet main ducts (red).

Air extracted from the Halls (grey) is partly recirculated and partly thrown away through the exhaust ducts and grilles (yellow).

All inlet and extract main ducts are structural and placed below ground floor level. They are accessible and lined with acoustic absorbing material to such an extent that noise penetrating from the plant room is adequately reduced.

Axial flow fans will be preferred to centrifugal fans. They do admittedly produce noise of an appreciably higher intensity, but the pitch is much higher too (600 - 1000 Hertz as against 50 - 100 Herts) which is a considerable advantage, as sound of high frequency is more readibly absorbed than that of low frequency.

The plant is divided into 5 main groups serving the following localities:

1. Major Hall and appropriate public space,
2. Minor Hall and   ditto   ditto,
3. Rehearsal rooms, offices and staff quarters adjacent to Major Hall,
4. Ditto adjacent to Minor Hall,
5. Restaurant.

A closer investigation into the occupation periods of the different parts of the building may indicate that a further subdivision is required.

From the longitudinal section will be seen that the inlet air is blown into the major hall through the ceiling over the permanent seats and through openings at high level in the walls at both sides of the stage. These latter openings are only required when additional seating has been placed on the stage.

The extract takes place through grilles under the permanent seats and at floor level in the wall at the back of the stage.
The fans have two-speed motors.

The amount of air handled at low speed corresponds to that required for an audience of 1825 persons, whereas the fans are to be on full speed when additional seating has been provided on the stage.

The air inlets and extracts to the stage are closed by automatically operated dampers controlled by the switch gear for the inlet and extract fan motors whenever the hall is being used for operas or other purposes which will require a stage.

A special extract system is provided in the upper part of the stage to create an air movement towards the stage away from the audience.

This plant, which has not been shown on the section, will only be started when the curtain has been raised.

We can give the following information about the proposed air conditioning system.

Both Halls can be considered as separate and independent buildings placed inside a system of concrete shells. This is a great advantage from the air conditioning point of view, in particular when cooling is required, as walls and ceilings of the halls are shielded against the direct heat from the sun. The concrete shells act as enormous parasols.

The solar energy transmitted through the shells can be eliminated therefore before it enters the auditorium. This can be done, either by natural or mechanical ventilation of the roof space or by placing cooling units above the auditorium. The most economical way of achieving this heat barrier can be determined only after a close examination of prevailing wind in connection with the solar radiation on the different parts of the structure.

Our preliminary calculations have been based on the following conditions:

External design conditions, summer:	90°F 42% R.H.
Internal conditions required, summer:	79°F 50% R.H.
External design conditions, winter:	50°F 70% R.H.
Internal conditions required, winter:	70°F 50% R.H.

Inlet air 2000 cubic feet of air per person per hour, or a total of 100.000 c.f.m. for Major Hall, corresponding to a rate of air change of five times per hour approximately.

The cooling necessary for the air conditioning is effected by a refrigeration plant consisting of a number of compressors, condensers and evaporators.

Direct-expansion should not be used, but chilled water coils will be suitable. The refrigerant could be Freon, and sea water should be used for removing the heat from the condensers.

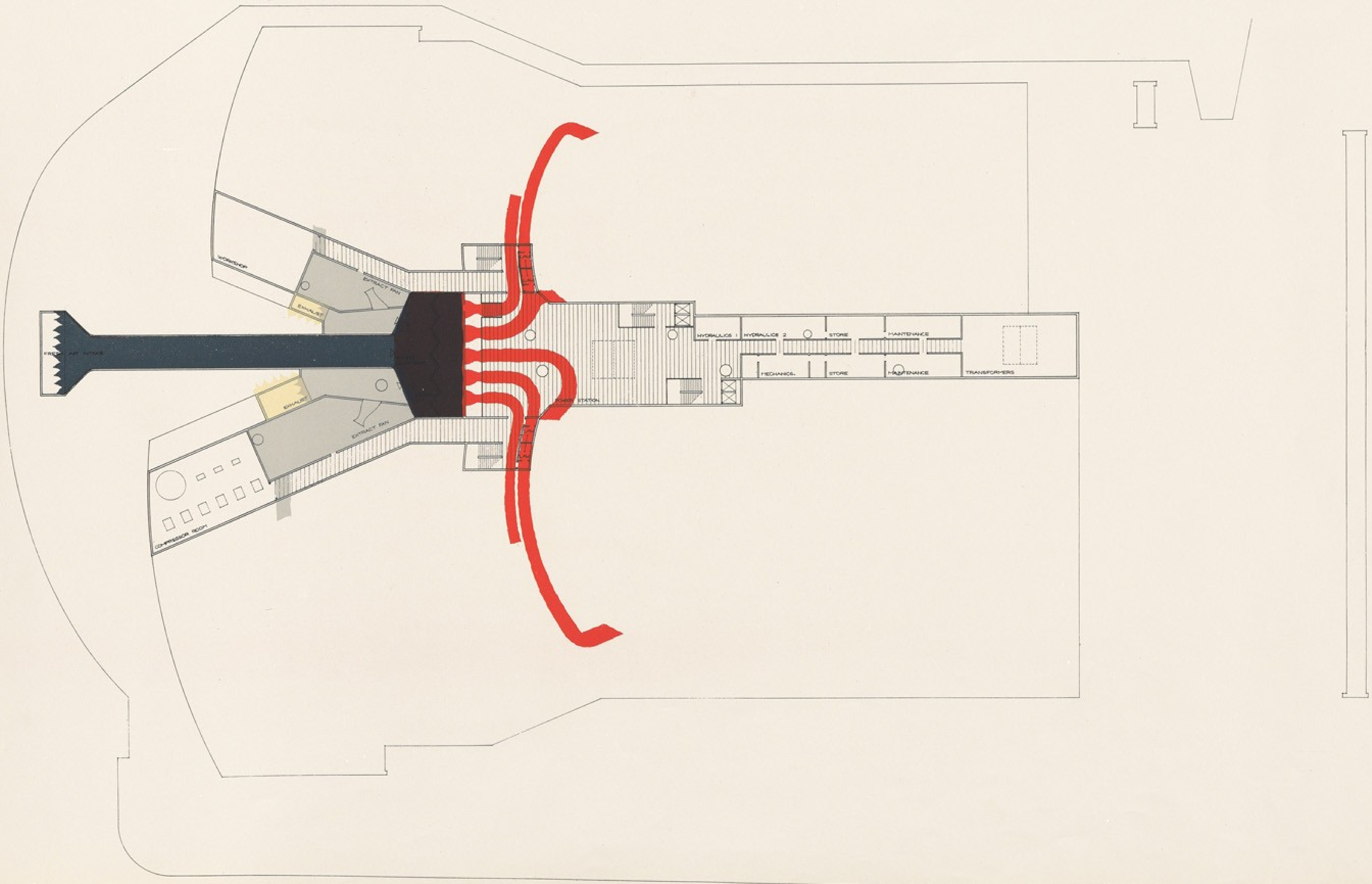
We do not consider it feasible to install a boiler plant inside the Opera building, and the possibility of utilizing the refrigeration plant on the heat pump principle to provide heating as well as cooling should be examined in detail. Should this prove uneconomical then we should recommend that a separate boiler house be erected in the vicinity of the existing warehouses.

The air conditioning system will be controlled automatically in order that the desired inside conditions can be maintained irrespective of the outside conditions. We shall propose electronic control for this purpose.

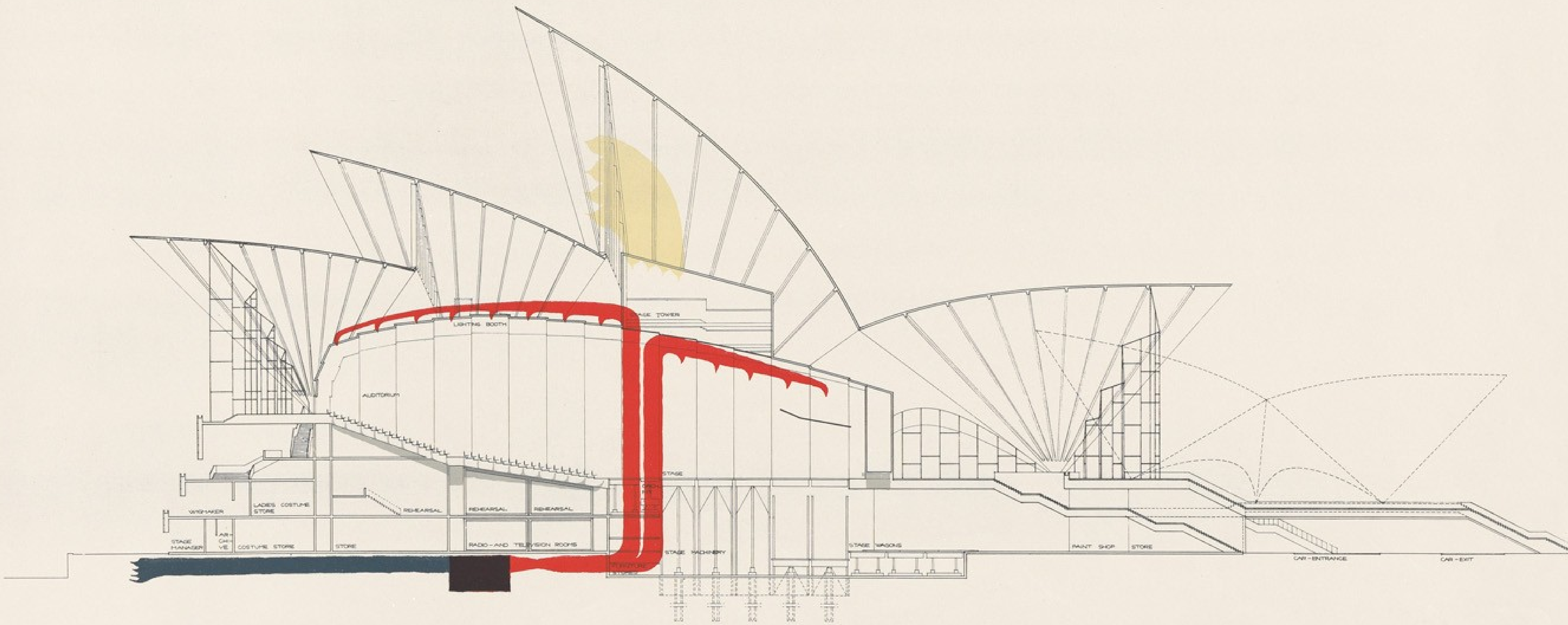
The detailed design of the plant will be based on the information given in the publications issued by the Commonwealth Experimental Building Station in Sydney in conjunction with the London County Council regulations concerning Places of Public Entertainment.

J.Varming

J.Varming .



BASEMENT FLOOR SCALE 1/32" = 1'-0"



LONGITUDINAL SECTION THROUGH MAJOR HALL SCALE 1/32" 1' 0"

E L E C T R I C A L   I N S T A L L A T I O N S.

The electrical services are closely related to the architectural treatment of the building and the detailed layout of the mechanical equipment. Consequently only brief outlines of the main dispositions can be given at this stage of the design.

Furthermore, a study of a number of electrical installations, such as lifts, clocks, telephones, facilities for radio and television transmissions, call and signal systems, fire detection and other items of vital importance, will have to be postponed until more details are available.

The total maximum load for power, lighting, etc. is estimated to be of the order 2000 kW. The electrical connection to the building should be a high-tension supply from the public electricity system.
Two high-tension cables, each with a capacity of approx. 2500 kW, should be provided. To reduce furthermore the possibility of power failure, these connections should, if at all possible, be taken off two separate sections of the supply grid.

The high-tension cables terminate inside the building in two high-tension circuit-breakers and the necessary metering system. The transformer room should be big enough for four transformers, each with a capacity of approx. 800 kVA, but not more than three transformers would have to be installed initially.

We recommend in accordance with present day practice for buildings of this character, the installation of a stand-by generator to maintain a reduced power supply in case of a break-down in the public supply system. We estimate that the stand-by generator should be of the order 500 kVA.
The transformers together with the high- and low-tension switch gear as well as the stand-by generator would have to be located in the basement, preferably adjacent to the compressor room.

A security lighting system supplied from a battery will have to be provided in accordance with the Building Regulations. We estimate that a battery of the order 200 Ah at 220 volts will be required.

The supply cables for the different electric motors in the basement should be run in cable trays at high level.

The vertical supply systems for power and lighting should preferably consist of prefabricated buss-bars from which panels for the outgoing feeds can be built up.

The lighting in particular forms an integral part of the architecture and must be studied as such.

It is, however, as a rule recommended to use incandescent lighting for all rooms; indirect lighting may have to be employed in a number of places.

It should be mentioned that the optical communication between the conductor of the orchestra and a chorus or other performers behind the stage will have to be the subject of a special study. This communication ought to be established by a closed circuit television system.

The disposition of the building near the water's edge, will give a striking enhancement to the exterior lighting which will spread out into the darkness in ever changing reflections from the water, as from a bright-lit liner gliding softly into port from the depths of the night.

M.Balslev

T H E A T R E   T E C H N I Q U E

In all theatre countries of importance a feverish experimentation is going on right now with new forms of the theatre and new devices for the purpose and employment of the play stage. The work on this is going hand in hand with the experiments on new dramatics and new expression forms for the actor's art. One result of this work can already now be established. Henceforth, we will have to play theatre in many a greater variety of forms than hitherto.

Until the last few decades, the work-shop of the theatre, the stage, had, in principle, not been subject to any change for 200 years or more - apart from development of the technical auxiliary equipment. The views concerning what sort of architectonic stage house one ought to play theatre in had stagnated. Now it is no longer so. The expression forms of the theatre art have grown richer. We have broken out of the snail-shell of the baroque-theatre and have discovered so many more ways in which to play theatre. That is why it seems the only right and natural thing to the theatre's artistic leaders, to stage managers and producers, that a theatre that is built nowadays must be so constructed that it is not tied down firmly to one playhouse form, but that it is a theatre house that lives and that can change form and architectonic atmosphere according to the changing theatrical forms whose development it makes possible. The forms in which the theatre can manifest itself are infinitely rich and this house must be able to serve these forms and permit them to develop freely. The play stages housed within the Sidney Opera and Theatre House should fill most of the demands that can be made for this purpose. From dramatic and lyric theatre of varying size and style to intimate chamber play- and studio-theatre - from theatre performed on an intimate central arena, with the audience placed in a circle around the play stage, to the show-play of the large arena. For the purpose of educating the new generations to the right understanding of the theatre's art, the studio-stage size might prove to be of particularly great importance.

The stage machinery system as worked out for the Sidney Opera and Theatre House is no doubt the only conceivable one under the given site premises and the composition of the theatre house in general, and one which at the same time provides the greatest number of variation possibilities with regard to the shifting of wings and set pieces and the technical arrangement in connection herewith, and offers the richest possibilities for solving, in a supply way, any technical or artistic problems that might arise.

The play plane, i.e., the stage floor, can, in reality, be said to be alive through its division into platform lifts, planes that can be raised and lowered, and stage conveyor movements in combination with the lifts. Stage scenery, or parts of stage scenery, can be set up in any size wanted and be mutually shifted. At the same time, the stage is large enough to accommodate largesized stationary scenery, thus reducing or eliminating the use of technical machinery. Particularly in the classical dramatics we have many examples of plays with a great deal of scene shifting, but where the producer demands that the scene shifting takes place while the play is on, and without mechanical assistance.

It is possible, for instance, with a considerable artistic advantage, to present a great Shakespeare performance, as, for example, "Hamlet" or "Macbeth", where the text calls for between 20 and 25 shifts of scenery, without any use at all of conveyors or platform lifts - merely through the composition of a sculptural scenery, that is, an irregular plane construction with horizontal and vertical forms that through a many-sided faceting lend themselves to the shifting scenes of the drama. In itself, such a plastic space scenery is what is called a neutral play stage, none of its formations representing anything recognizable or evident - when, however, the actors give life to the stage in the shifting scenes of the plot, these abstract formations change, in the imagination of the audience, into banquet halls, battle fields, entrance halls, cellars, landscapes, ramparts, etc.

The proposed stage machinery may also be used when it is a question of partially changing such a sculpture scenery, set up to remain on stage through the whole performance. Bigger or smaller parts of such set pieces may be lowered on platform lifts and replaced by new components pushed in on stage conveyors.

It is not necessary, of course, that such a disappearing or new-added part of a stage construction is of the same size as the stage lift's total surface area. One is not bound to the maximum capacity of the lifts or the conveyors but can, according to requirements, reduce the extent and volume of the set details that have to be released from the scenery in its entirety.

In principle, there is hardly any limit to the number of settings that, with the system here adapted, it is possible to compose and present successively. Merely by applying the circular motion of the five big stage conveyors over the stage lifts the system functions as a sort of perpetuum mobile. The stage setting is made ready on its conveyor down in the stage basement, is pushed onto the platform lift in the background of the stage, raised to stage floor level, rolled forward on its rails to the stage opening, lowered on the forestage lift to the basement, demounted, and rolled back to the original position for a new set mounting.

The platform lifts function individually or coupled together - two and two, f.inst. On such a couple, operated together, a setting is built up, for example, the banquet hall in "Hamlet". When this is lowered into the basement the ramparts of the castle of Kronborg are raised simultaneously on the platform lift farther back. This simultaneous soft shifting of two settings can, of course, be utilized also for an artistic and dramatic effect, and not only as a supple technical arrangement.

The available stage area has not been large enough to permit, to advantage, the installation of a revolving stage of the size required to make it really effective. A theatre that as technical equipment has only a revolving stage is always faced with the problem that sets built up on the revolving stage are crowding each other and obscuring the free perspective of each other toward the horizon. From this point of view, the system of individually independent settings on conveyors or platforms is highly preferable.

We can imagine how, for example, "Peer Gynt" by Ibsen can be solved essentially by applying the stage technique which the dramatic stage will have at its disposal - that is, if it is not preferred to perform a play of that size on the opera stage. "Peer Gynt" consists of about 26 settings. The 10 scenes of the First Act depict mostly the flight of Peer through the Norwegian mountain world. The landscape is changing all the time as Peer walks along.

First of all, we are working with magic lantern projectors on the cyclorama. The fantastic mountain world looms bluish in the unattainable distance. On the stage lifts, plastic mountain and plateau formations have been built up and combined with the lantern slides of the cyclorama, so that the illusion is created that we are on the highest tops of the mountains. The plastic mountain formations are distributed over the different platforms, so that these, to a certain extent, may be lowered or raised independent of one another. Peer Gynt wanders in the mountains - he walks up a slope on the foremost platform lift - at the same time a platform behind it rises with new mountain formations, namely, the new landscape which he sees when reaching the top of the hill. Also the movements of these lifts may adequately be combined with a simultaneous changing in the nature of the lantern slides of the cyclorama.

By means of placing the stage platforms on individually different levels the feeling of the stage floor as a stationary level is eliminated. In the same way in which the modern theatre has worked to treat the theatre stage as a room with horizontal depth effect - with the third dimension - the platform system permits us to work also with the possibility of the stage for vertical depth effect. The scenery world of the drama continues also below what we called previously "the boards that represent the world".

It is self-evident what extraordinarily gratifying effects may be obtained through opening part of the stage, and from the depth below upward to the stage-area arranging entrance schemes for actors and extras - whether it now be the giant stairs of the Capitol in "Julius Cæsar" or the forest scenery of "A Midsummer-night's Dream". By means of a limited number of cleverly placed extras it is possible to obtain the full illusion of an interminable crowd of people that continue downward to the foot of the Capitol stairs, or below the palace of Oedipus and Agamemnon. And in the Midsummer-night's Dream the field may open and from the underworld below allow an interminable procession of elves, fairies, goblins and wood nymphs to float mistily up into the human world.

The Midsummer-night's Dream has one problem often difficult to solve, i.e., the castle of Theseus that appears only in the beginning and the end of the plot. On a stage like the present one the problem is easily solved, however. The entire big wood, the play's dominating locality, covers constantly the whole stage area. The castle is built up on the foremost platform lift and emerges in front of the wood which is hidden by the castle set. First and foremost the technical construction of the large stage allows for excellent possibilities of acting for the producer. It may be used as an "ordinary" theatrical stage for the traditional opera repertoire and for large musicals and shows, i.e. when the stage is separated from the auditorium by the proscenium wall with its curtain and by using the cyclorama and the stage conveyors.

It may moreover be transformed to a gigant arena when the proscenium with its lighting tower etc. disappear at the sides, thereby eliminating the entire boundary between the stage and the auditorium. On such occasions the stage floor is lowered hydraulically to the horizontal level of the auditorium floor - and not only the part of the stage floor which comprises the stage lifts but also the area between these and the side walls of the stage.

On this arena large shows and revues such as "Round the World in 80 Days" may be shown and with just as great an effect arena stage performances of dramatic and lyrical repertoire may be given.

It is possible to let the stage floor remain sunk at one level, and one may also utilize the lifts and as required "cut the arena stage short" into various levels and heights, all easily changed while the performance is going on. Consequently nothing will prevent suddenly letting a large plastic decorative construction appear from the underworld, or wherever one wishes, onto the open arena stage, thus producing in show-revues a most dazzling effect.

During the above mentioned alternative the public are assumed to remain in the ordinary auditorium - i.e. only on the one side of the arena. It would, however, also be quite easy to utilize half of the former stage area as an arena stage, and to arrange amphi-theatrical pit stalls. In this way a stage space is created in the form of an arena which lies in the middle between two audience pit stalls.

In point of fact this latter form of a play-stage is greatly developing as a new form of theatre, and everywhere such experiments have proved artistically to be a very popular feature.

It is obviously not necessary to point out how an arena stage with the above mentioned possibilities of variation, also may be used with great advantage as an arena for various kinds of celebrations, meetings and gatherings outside of the sphere of the professional theatre.

Sandro Malmquist
Sandro Malmquist

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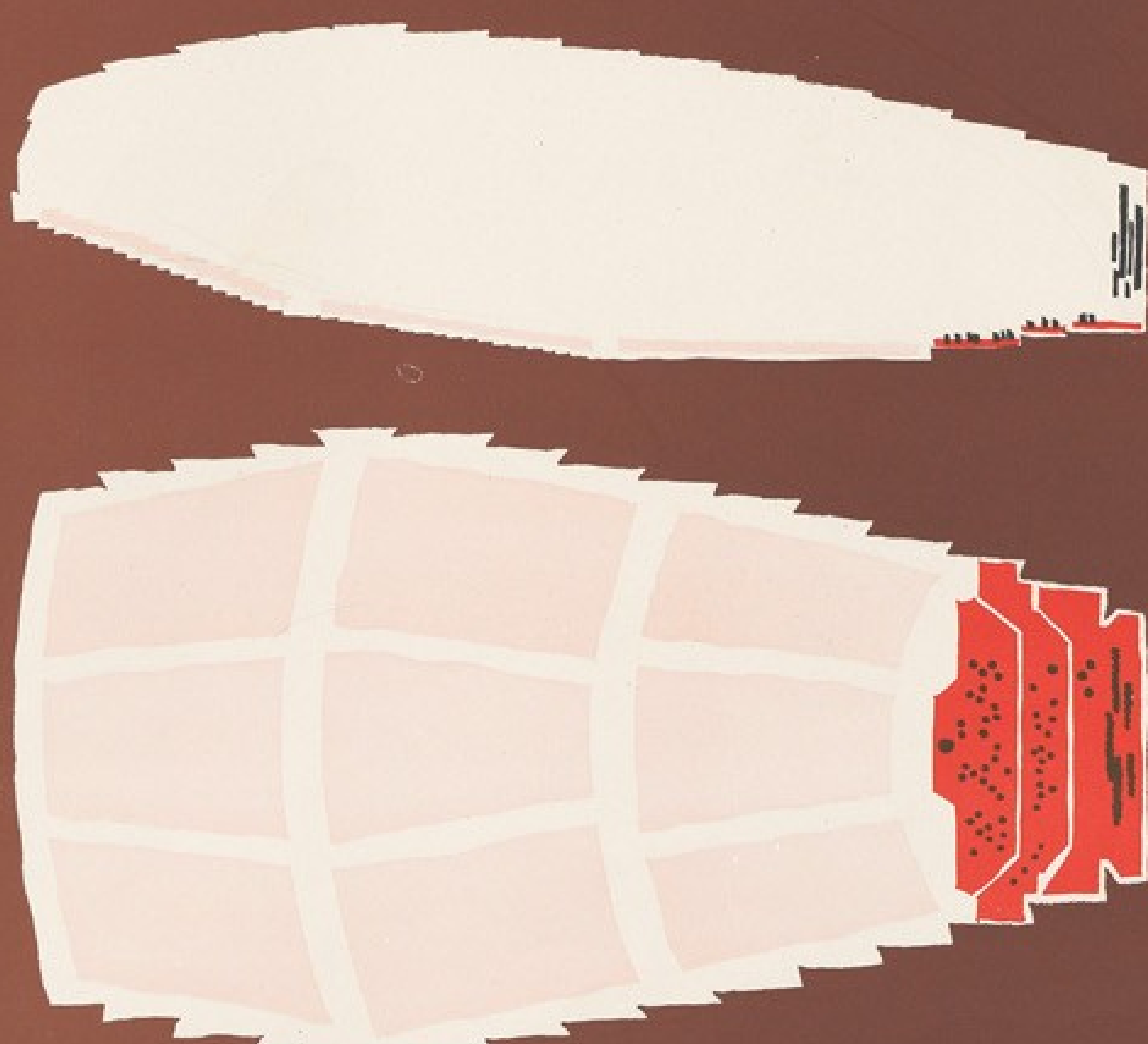
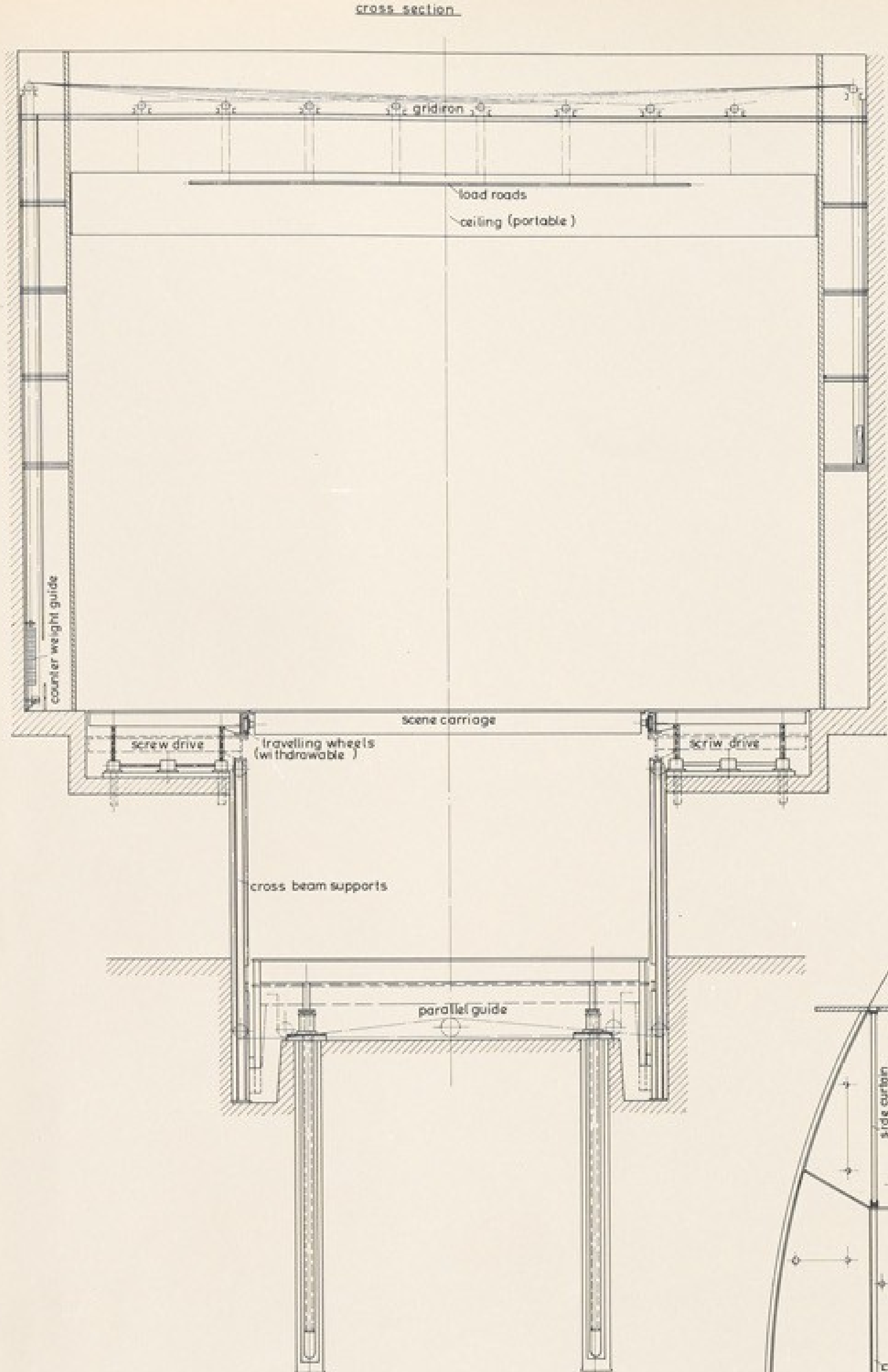
MAJOR HALL AS ARENA THEATRE

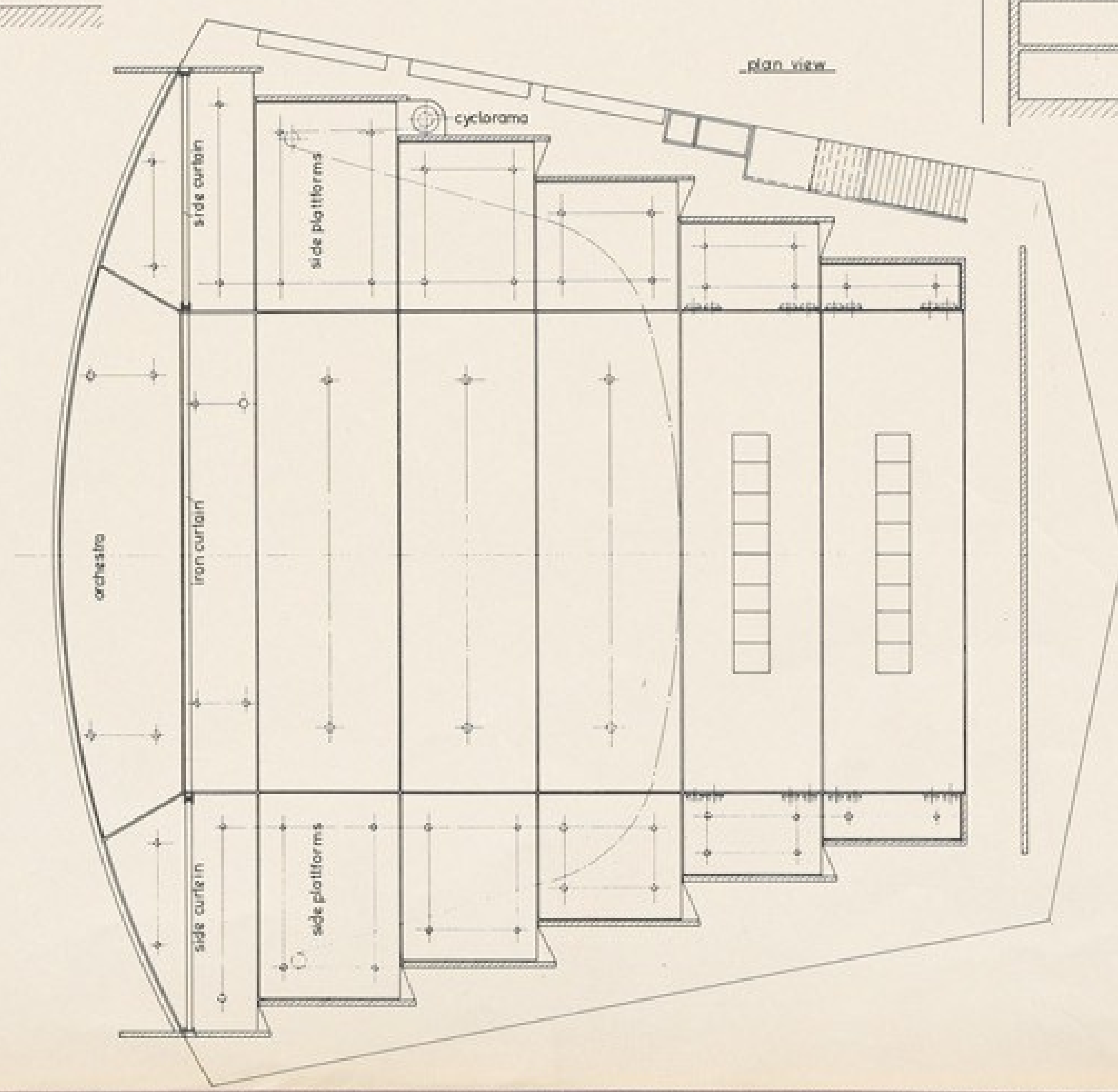


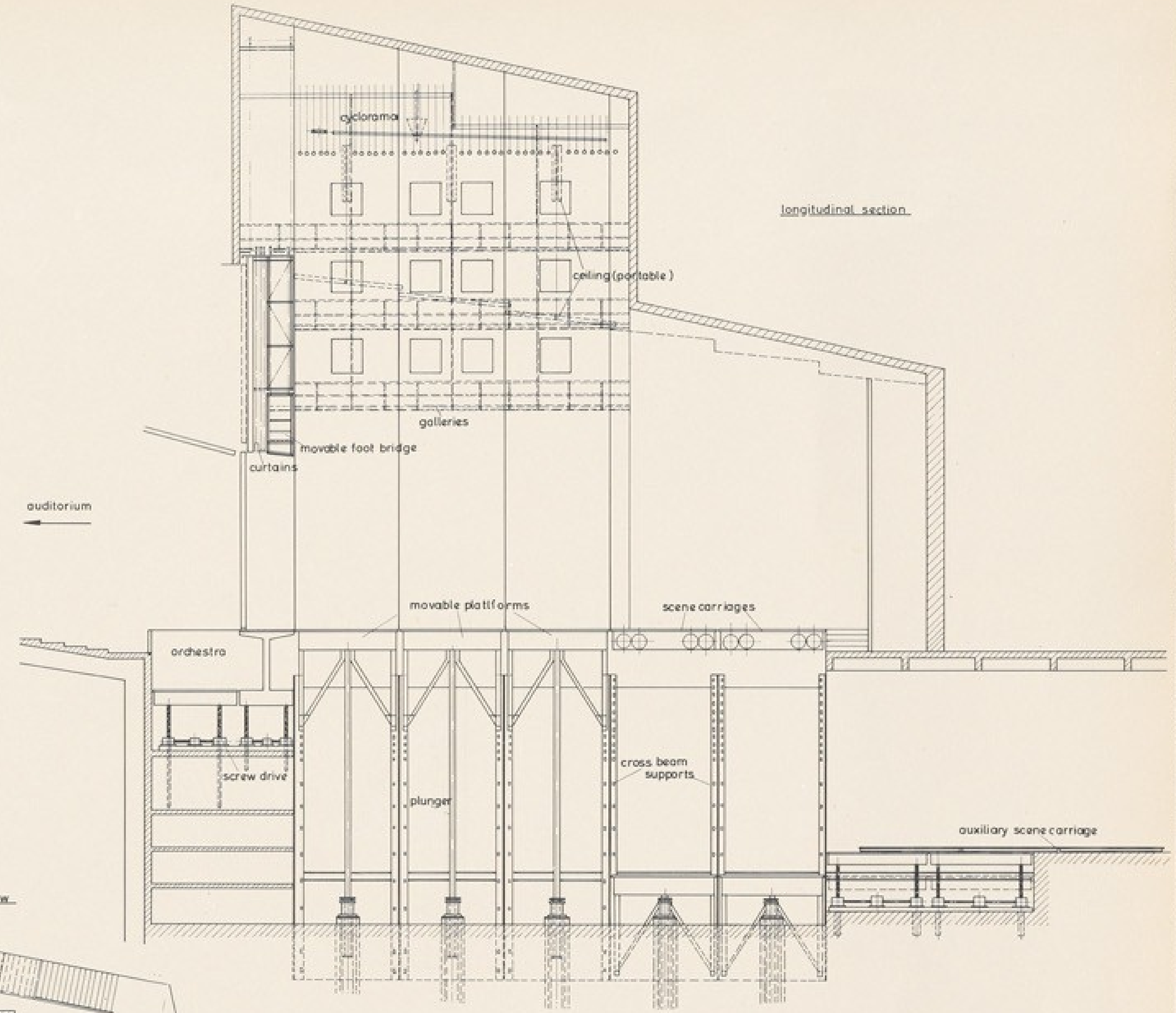
MAJOR HALL AS CONCERT HALL

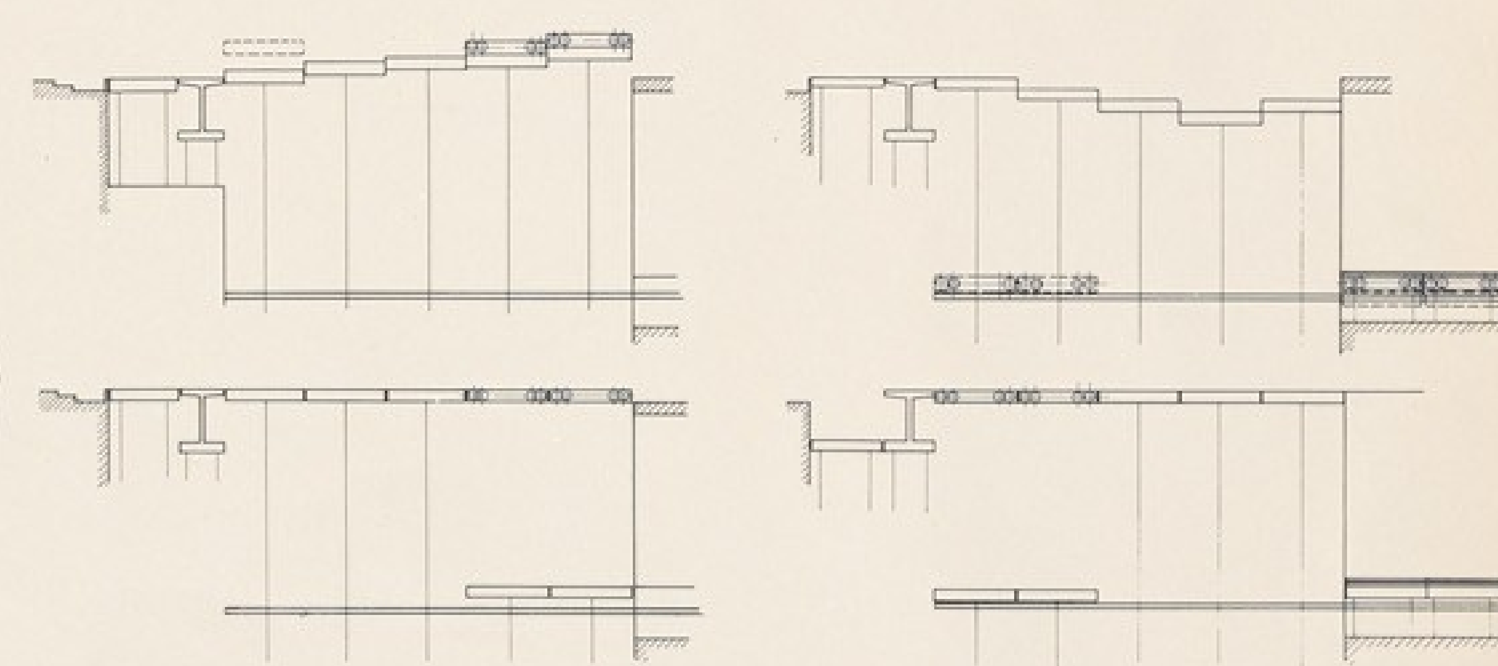
MAJOR HALL AS OPERA THEATRE

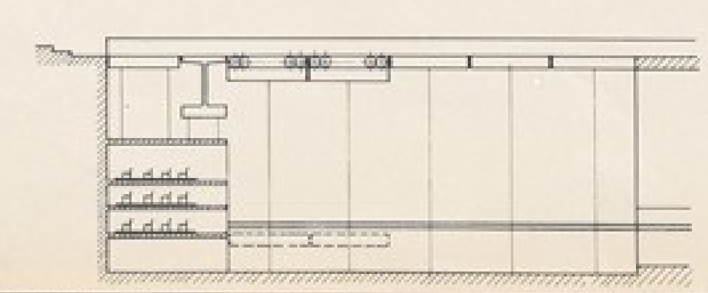
VARIOUS USES OF MAJOR HALL SCALE 1/32" = 1'-0"











Anfrage: 935 810

	Day	Name
Design	3.1.58	Lechler
Checked		
Standard		

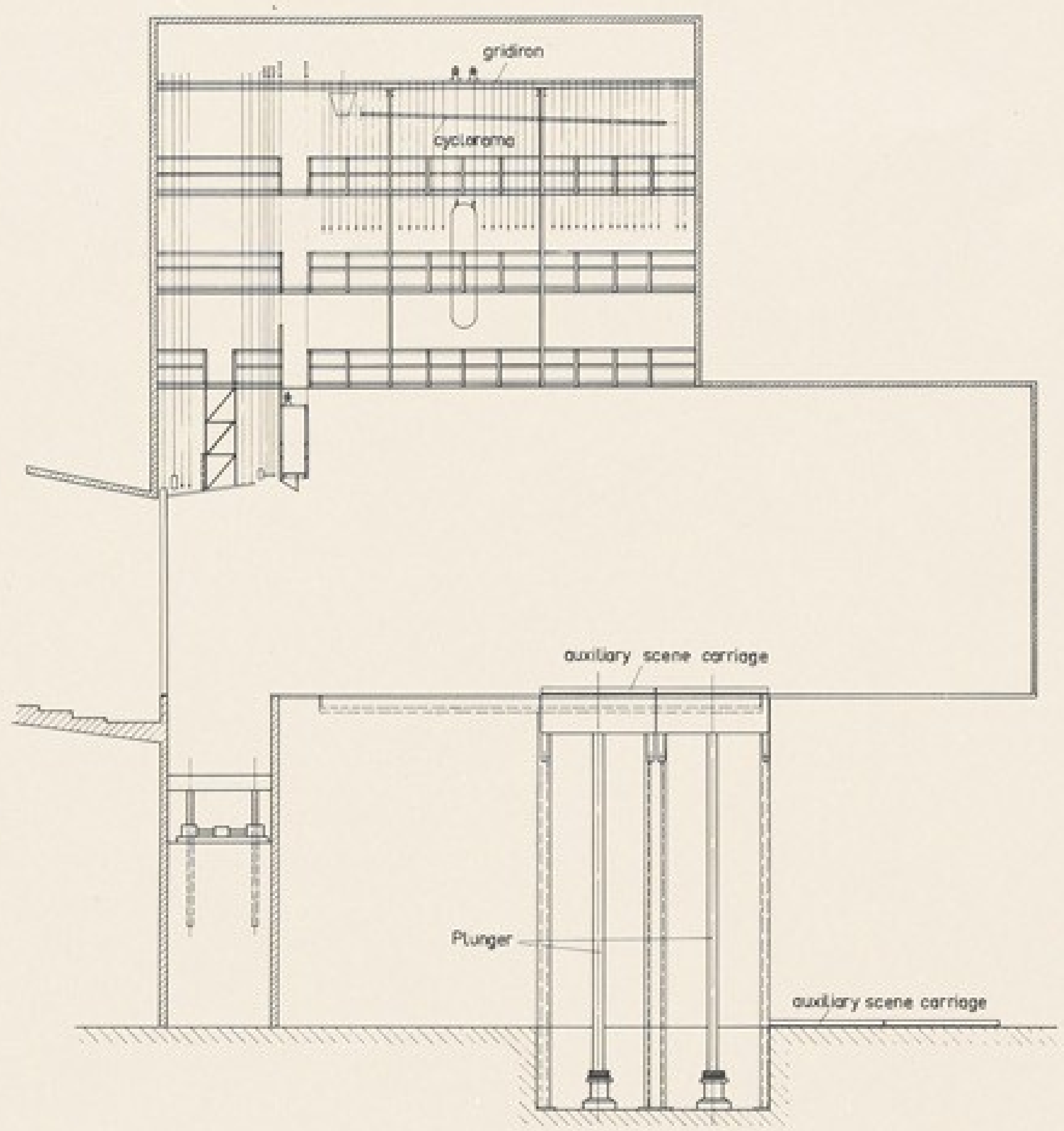
Scale 1/16"=1'

Parts
National Opera House Sydney
stage machinery
(sheet : 1)

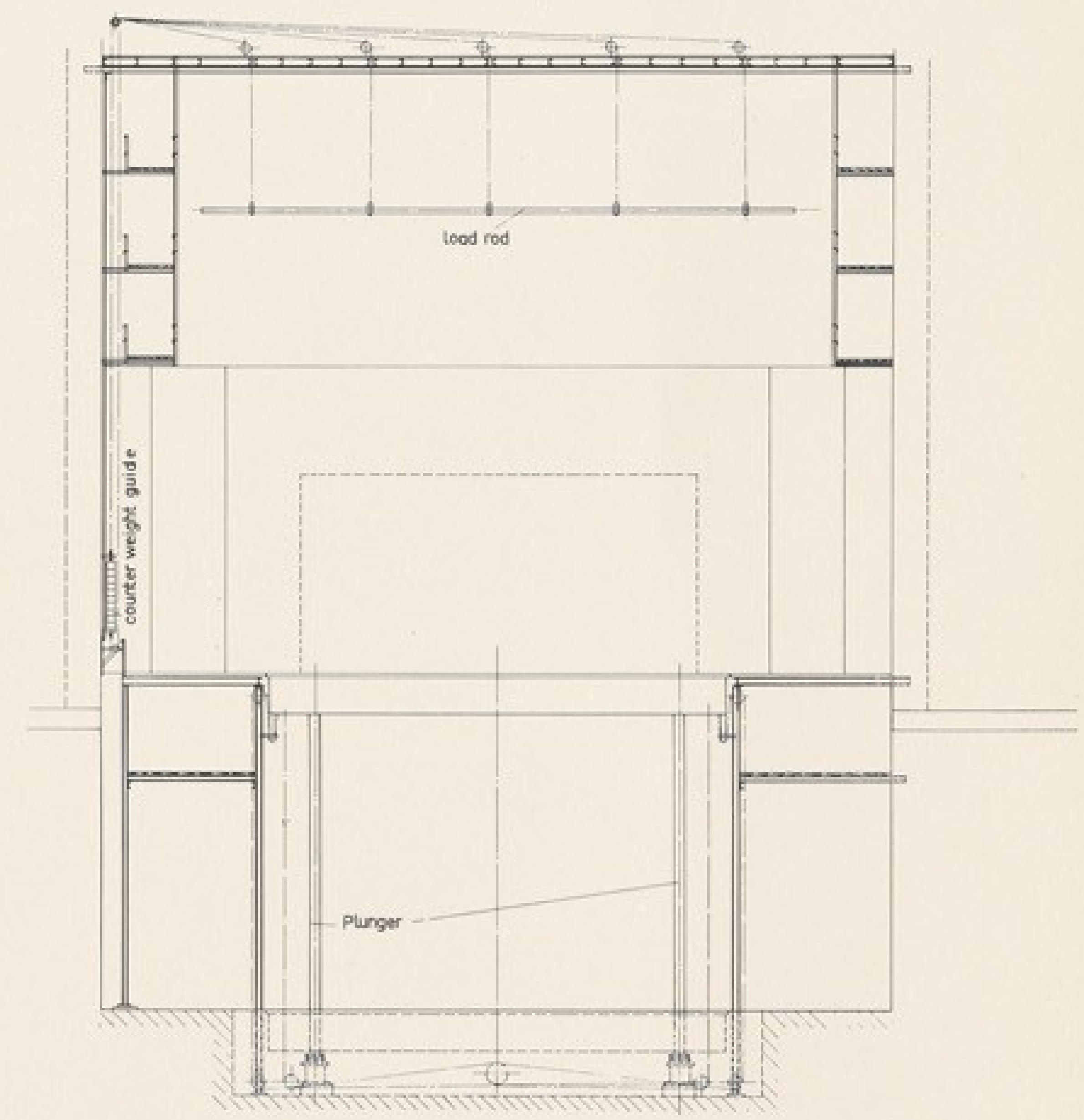
M·A·N
WERK GUSTAVSBURG

Bm: 285066

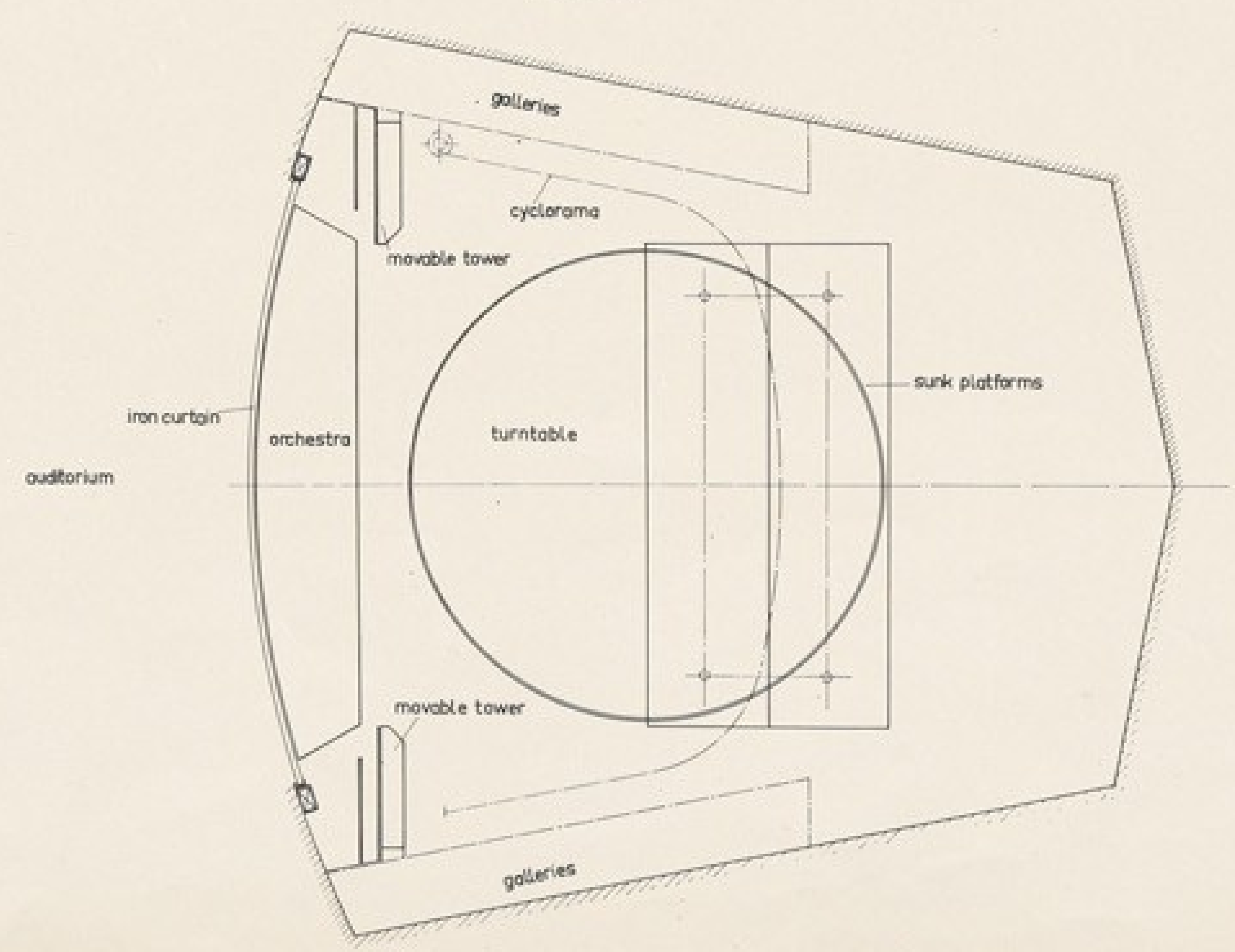
longitudinal section



cross section



plan view



Anfrage: 935810

	Day	Name
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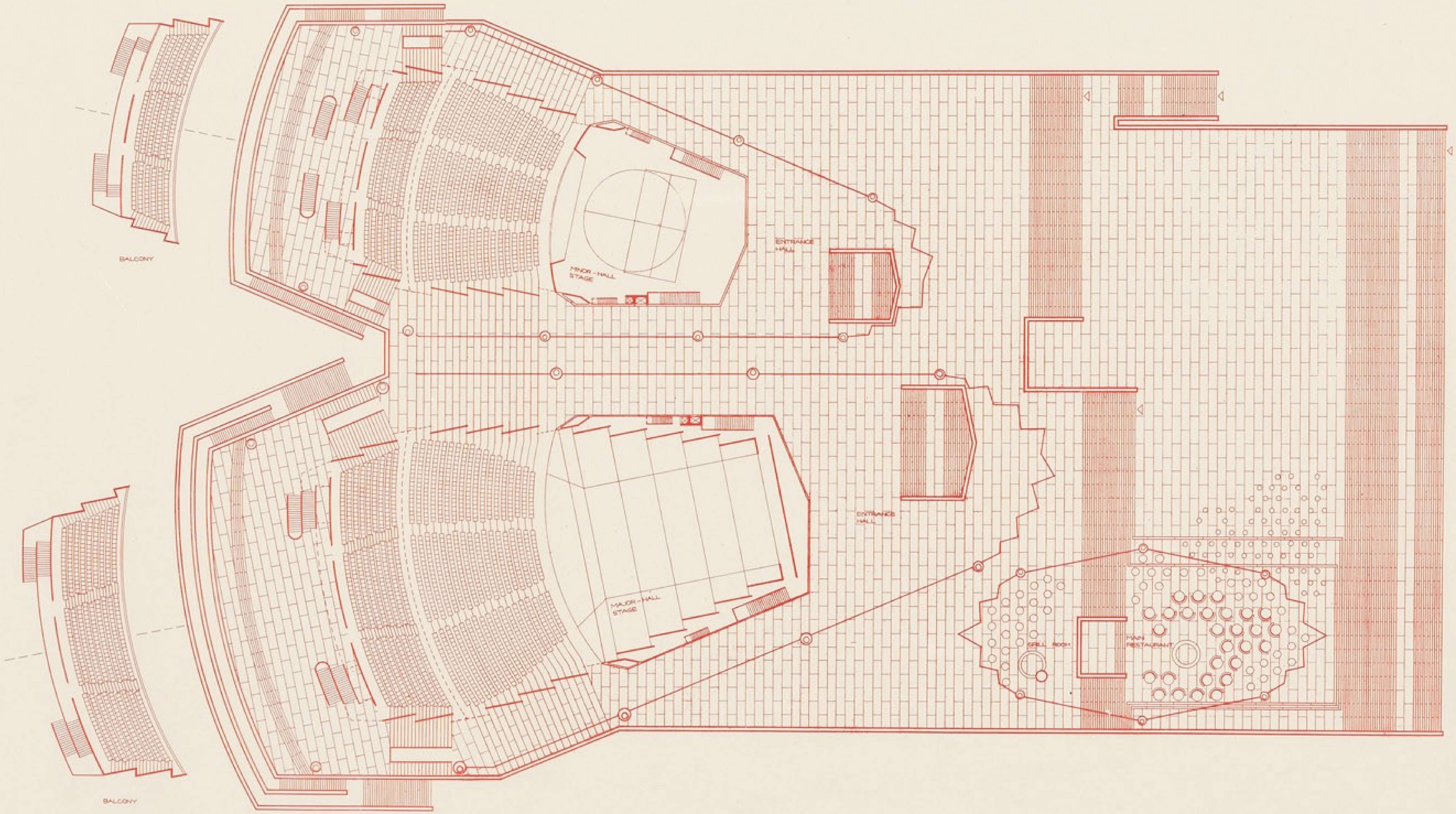
Checked		
Standard		

M·A·N

Scale: 1/8"=1'

Parts: SYDNEY NATIONAL OPERA-HOUSE
MINOR HALL
stage machinery

Bm 286065



ALTERNATIVE BALCONY PLAN SCALE 1/32" : 1' 0"