Apollo Theatre, Shaftesbury Avenue
Structural engineering notes on ceiling collapse
Prepared for Westminster City Council
December 2014
Alan Baxter

1.0 Introduction

1.1 The Apollo Theatre is located on Shaftesbury Avenue in the City of Westminster, London.

1.2 In December 2013 part of the ornate plaster ceiling above the main auditorium collapsed. Alan Baxter & Associates (ABA) have been asked by Westminster City Council (WCC) to work in conjuction with the plaster specialist, Richard Ireland, to report on the likely causes of the collapse, the form and condition of the remaining ceiling construction and to recommend a strategy for the repair of the ceiling.

1.3 These notes focus on the structure that supports the ceiling. For information about the plaster ceiling itself see information from the historic plaster expert, Richard Ireland, with whom we have collaborated in looking at this matter.

1.4 These notes are based upon observations made on site by ABA during December 2013 and February 2014, and our knowledge of structures of comparable age and form of construction.

2.0 A brief history of the Apollo Theatre

2.1 The Theatre was constructed in 1901 by the architect Lewen Sharp and is Grade II listed. The listing description, see Appendix B, suggests that a refurbishment was carried out in the 1930s.

2.2 The auditorium space consists of the stalls and three cantilevered balconies. There is an attic above the auditorium.

3.0 General description of the ceiling construction and its supporting structure

3.1 Our understanding of the form of the ceiling construction and supporting structure is shown on the sketches in Appendix B. REPORT REDACTED.

3.2 Structures generally have a clear hierarchy in their role, usually related to the discipline of how the designer and builder approached the project. At the Apollo the hierarchy of the main structure and the materials used are conventional. However, the complex three-dimensional shape of the ceiling has created a different approach for the actual ceiling construction which is ad hoc and illogical. This is not part of the main structure of the building, even though it contains timbers which have to perform a structural role. This ad hoc arrangement was all built by the ceiling installers, not by the builder of the main structure.

3.3 The first order structure is at high level where the main structure of the Theatre consists of steel roof trusses which span over the main auditorium and are supported on the external walls. The bottom chords of the trusses support the second order timber deck

which forms the floor of the attic space. These elements are all part of the main building structure and would have been erected by the main building contractor.

3.4 Beneath the bottom of the trusses there is the third order structure - a grillage of steel beams. These are supported from the roof trusses with steel hangers and they roughly describe the shape of the fibrous plaster ceiling below. This layer has a logical form and, again, would have been erected by the main building contractor.

3.5 Below the steel beams is an arrangement of timbers which is fixed directly to the main structure above with bolted timber hangers, bolts and possibly nails. These are arranged in a roughly radial pattern and have a fairly logical form. This layer would likely have been constructed by the main building contractor and it forms the basic carcassing that the ceiling installers would then fix the fibrous plaster ceiling to. To differentiate them from the timbers below, these are referred to in this report as the primary timbers.

3.6 Below this main carcassing is the ceiling construction which is far less logical. There is an arrangement of timbers to which the fibrous plaster ceiling panels are directly fixed to, or hung from. Due to the complex geometry of the ceiling these are in several layers and they are arranged in a very ad hoc way. In this report we refer to these as the secondary timbers and these would have been erected by the ceiling installers. These form layer one of the ceiling construction.

3.7 The ad hoc arrangement of timbers referred to above is likely to have been installed by the ceiling installers on an as-required basis, i.e. if further secondary timbers were needed to support the fibrous plaster panels, these were put in by the ceiling installers as they went along. These secondary timbers were generally hung from the structure above by wadding ties formed of hessian soaked in plaster of Paris, i.e. the timbers were wadded to the main structure, the primary timbers, or to other secondary timbers on an empirical basis. The fibrous plaster ceiling panels are then wadded to the secondary timbers. This was common practice for the construction of ceilings at the time the Apollo ceiling was built.

3.8 There are some wadding ties added between some primary timber members and the main structure. It is not clear why this was done, but it may have been because the ceiling craftsmen considered that the bolted and nailed fixings of the primary timbers were not adequate to support the loads that their method of ceiling installation imposed on these members. Again this all appears to be ad hoc and empirical, based on the experience of the ceiling installers.

3.9 The fibrous plaster ceiling panels themselves contain timber laths and battens embedded into them around which there are some wire ties which connect to the main structure above. The panels are layer two of the ceiling construction.

These wire ties appear to be original, as some of them are embedded into the timber laths used in the construction of the fibrous plaster panels. It appears that these wire ties were used to hang the ceiling panels in place and adjust them to achieve the complex ceiling geometry while the secondary timbers and wadding ties were installed. These wires all have four strands and are consistently wound to tighten them up and achieve the adjustment required. The fact that some of the wires pass around laths in the panels means that they could not have been intended to act as long term ceiling supports. The laths are small in cross section and are not able to support high loads which would exist if all of the ceiling load, including the added secondary timbers, was to be taken by the wire ties.

3.10 There are also some wire ties between secondary timber members or wound between secondary timbers and primary timbers or the main structure. These are also four-strand wires in the same way as the ceiling panel wire ties described in 3.9. The likelihood is that these too were used to temporarily locate and adjust the ceiling construction timbers until the hessian wadding ties were added.

3.11 Our conclusion is that the main ceiling support ties are the hessian wadding ties. The wire ties are secondary but all remain in place and so contribute to a degree to the support of the ceiling construction.

3.12 There are a few "two strand" wire ties, which have been drilled and anchored via discs through the plaster of the ceiling itself. These are likely to have been installed as part of some post-original remedial works.

3.13 In summary, the ceiling construction at the Apollo Theatre is typical for the time at which it was built. The structure supporting the ceiling construction has a clear hierarchy and a logical form and would have been constructed by the builders of the main building structure.

Due to the ceiling's complex three dimensional geometry, layer one of the ceiling construction, the secondary timbers, is arranged in a far more ad hoc fashion. It was constructed by the ceiling installers and is hung from the structure by hessian soaked in plaster of Paris – wadding ties. The ceiling construction relies heavily on these wadding tie connections for support.

4.0 Observations of the debris and what remains of the collapsed ceiling

4.1 The debris on the floor and seats of the auditorium comprised the remnants of fibrous plaster panels, some secondary timbers, disintegrated plaster and dust. There were a few wire ties in the debris. There was evidence of some remnants of wadding ties. The debris was dry.

4.2 In the void above the section of the ceiling that collapsed the primary timbers remain suspended from the steel structures above and some of the secondary members remain connected to the primaries. Several broken wadding ties can be seen.

4.3 The detachment of the ceiling occurred as a result of wadding ties between secondary and primary timbers and between the fibrous plaster panels and the ceiling timbers failing. Wire ties remain and in general the loops where they were wound around the timbers are still there. It is clear that where the wires ties were connected to laths within the fibrous plaster panels, when the collapse occurred the laths fractured.

4.4 The timbers and steels themselves appear in reasonable condition.

5.0 Observations of the form and condition of the remaining ceiling construction

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5.2 The timber hanger connections between the primary timbers and the steel structures above appear in reasonable condition and show no signs of failure.

5.3 The primary timbers and main steel structure themselves appear in reasonable condition.

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5.5 REPORT REDACTED

6.0 <u>Discussions of possible factors contributing to the collapse of the ceiling</u>

6.1 The wadding ties connecting many constituent parts of the ceiling construction together are made up of plaster of Paris with hessian reinforcement. In this arrangement, the hessian contributes to the tensile capacity of the ties and the plaster of Paris is the binding material that holds them in place and gives the ties their shape. Hessian is a natural, organic material that suffers from time-dependent degradation and it is likely that the hessian in some of the ties has degraded leading to those ties fracturing. Richard Ireland, the plaster specialist, with whom we are collaborating, has confirmed that time-related degradation of hessian in these situations is known to be an issue.

6.2 It is likely that these wadding tie failures were progressive, i.e. they did not all fail at the same time. When this progressive failure was taking place, loads of the ceiling would have been shed to other wadding ties or the wire ties up to a point where the remaining arrangement of ties no longer had the capacity to support the loads, leading to the failure of part of the ceiling. The wire ties connected to laths in the ceiling panels have a capacity that is severely limited by the size of the laths to which they are tied. It is clear that a number of such laths broke during the collapse of the ceiling.

6.3 A known cause of problems with hessian re-inforced plaster is water and moisture. Where there are roof leaks, water ingress can lead to ceiling failures and a failure of hessian wadding ties. REPORT REDACTED

6.4 Theatres get very hot when they are full during performances and the audience breathing releases moisture into the air which, because of the heat generated, rises to the top of the theatre. This may create a harmful environment for a material such as hessian and could accelerate the natural degradation process.

6.5 According to media reports and witness accounts on the evening that the collapse occurred, a thunderstorm was in progress in the surrounding area. Several thunder shocks are reported to have occurred. If this did occur at the Apollo, then it is possible that the reverberation could have disturbed the remaining highly loaded wadding and wire ties and acted as a trigger for their failure. However for this to be the cause, the ceiling would have been on the point of failure and almost certainly would have collapsed at some stage soon after this.

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8.0 Structural engineering notes on the inspection and certification of fibrous plaster ceilings

8.1 As the licensing authority for theatres in Westminster the WCC require that ceiling certificates be obtained every three years.

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8.3 REPORT REDACTED

8.4 Moving forward, we advise that due to the severe consequences of a collapse, from a structural engineering perspective, much more rigour is needed in the inspection procedures for fibrous plaster ceilings. Ceilings should be inspected from both above and below and the constituent parts described and sketched for future reference. Photographic records should also be taken. Caveats on reports should also be carefully considered and not generally be accepted.

8.5 We believe that the guidance for inspections should be more demanding and prescriptive and that all theatres should be encouraged to get to grips with any of the above issues that are not fully understood.

8.6 There needs to be a clear understanding and record (including sketches) of the construction of the ceiling and how it is supported off the main structure of the building. This needs the input of a plaster specialist working with a structural engineer. It is unlikely that such records exist. In our view they should be the starting point for any future inspection and maintenance regime for such ceilings.

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8.8 Where fibrous plaster ceilings involve a complex arrangement of fibrous plaster panels, timber sub-frames, wadding ties and wires (some or all of these), special care and attention is needed to understand their construction and how they are supported off the main structure.

8.9 Where there is evidence of failure of wadding ties in such ceilings, consideration should be given to the consequences of further wadding tie failures. A structural engineer should be involved in this consideration. The option of complete re-support of a fibrous plaster ceiling construction off the main supporting structure above it should be considered, as this may be the only reliable method of safely supporting such a ceiling construction.

Appendix A
Listing Description

List Entry Summary

This building is listed under the Planning (Listed Buildings and Conservation Areas) Act 1990 as amended for its special architectural or historic interest.

Name: THE APOLLO THEATRE

List Entry Number: 1236173

Location

8, ARCHER STREET W1
THE APOLLO THEATRE, RUPERT STREET W1
THE APOLLO THEATRE, SHAFTESBURY AVENUE W1

The building may lie within the boundary of more than one authority.

County: Greater London Authority
District: City of Westminster
District Type: London Borough
Parish:

National Park: Not applicable to this List entry.

Grade: II

Date first listed: 28-Jun-1972

Date of most recent amendment: Not applicable to this List entry.

Legacy System Information

The contents of this record have been generated from a legacy data system.

Legacy System: LBS

UID: 427104

Asset Groupings

This List entry does not comprise part of an Asset Grouping. Asset Groupings are not part of the official record but are added later for information.

List Entry Description

Summary of Building

Legacy Record - This information may be included in the List Entry Details.

Reasons for Designation

Legacy Record - This information may be included in the List Entry Details.

History

Legacy Record - This information may be included in the List Entry Details.

Details

CITY OF WESTMINSTER SHAFTESBURY AVENUE W1
TQ 2980 NE The Apollo Theatre
71/54 (including No 8 Archer
28-6-72 Street)
GV II
Theatre,1901 by Lewen Sharp with sculptured work by T. Simpson. Stone faced, plain brick to Rupert Street and Denmark Street. Shaftesbury Avenue front in a Free Renaissance style. 3 main storeys and a tall attic. 3 major bays wide, the outer two as pavilions with shallow canted fronts. Arcaded ground floor foyer and gallery-circle entrances, under glass canopy supported on elaborate ornamental iron brackets. 1st floor central loggia and pedimented flanking windows. Attic storey above main entablature, with enriched oeil de boeuf windows and crowning cornice. The pavilion attics are treated as short circular turrets with shallow domes, rather Art Nouveau in character and are enhanced by figure sculpture of heroic scale. Rich interior (slightly simplified by Schaufelberg in 1932) with foyer and ante-room to Royal Box; the auditorium with elaborate plasterwork in "Louis XIV" style. 3 cantilevered balconies flowing into the serpentine fronts of richly ornamental tiers of boxes flanking the proscenium - single box at stage level, pairs at dress and upper circle levels with modelled terms supporting the gallery "box" above; architraved proscenium with figure relief composition to tympanum over. Richly ornamental shallow domed ceiling on pendentives, etc. Lewen Sharp's only theatre, although he also altered the Camberwell Palace of Varieties in 1908.

Listing NGR: TQ2962280839

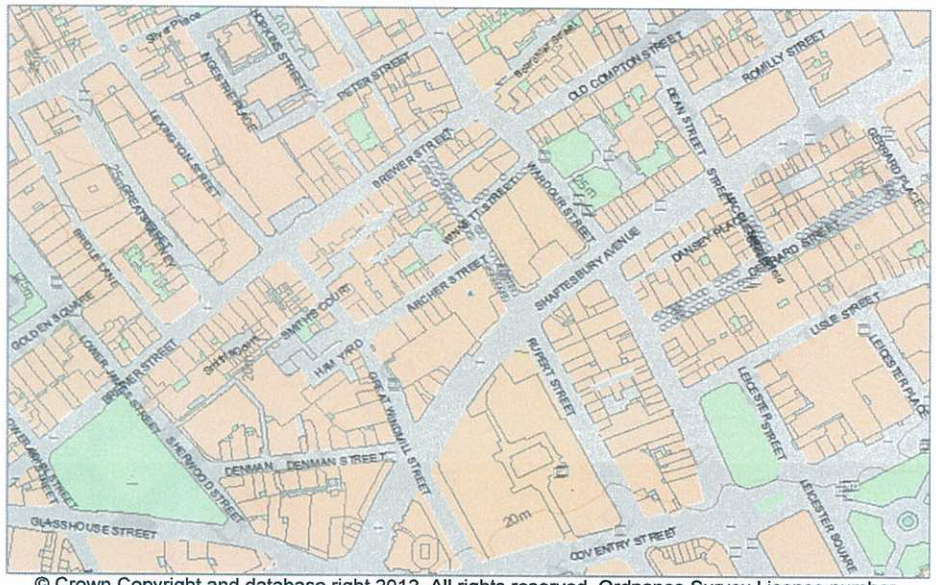
Selected Sources

Legacy Record - This information may be included in the List Entry Details.

Map

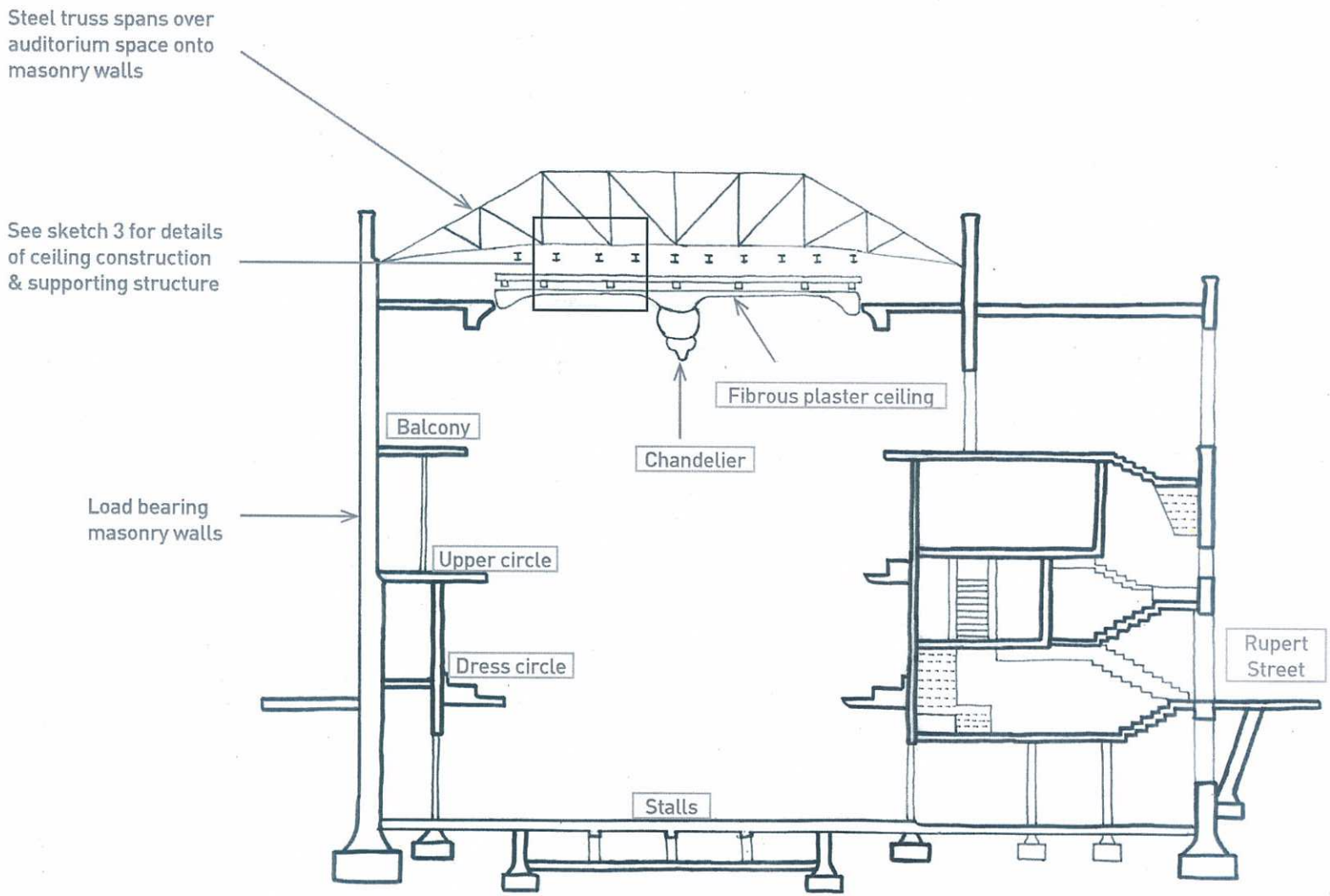
National Grid Reference: TQ 29622 80839

The below map is for quick reference purposes only and may not be to scale. For a copy of the full scale map, please see the attached PDF - 1236173.pdf

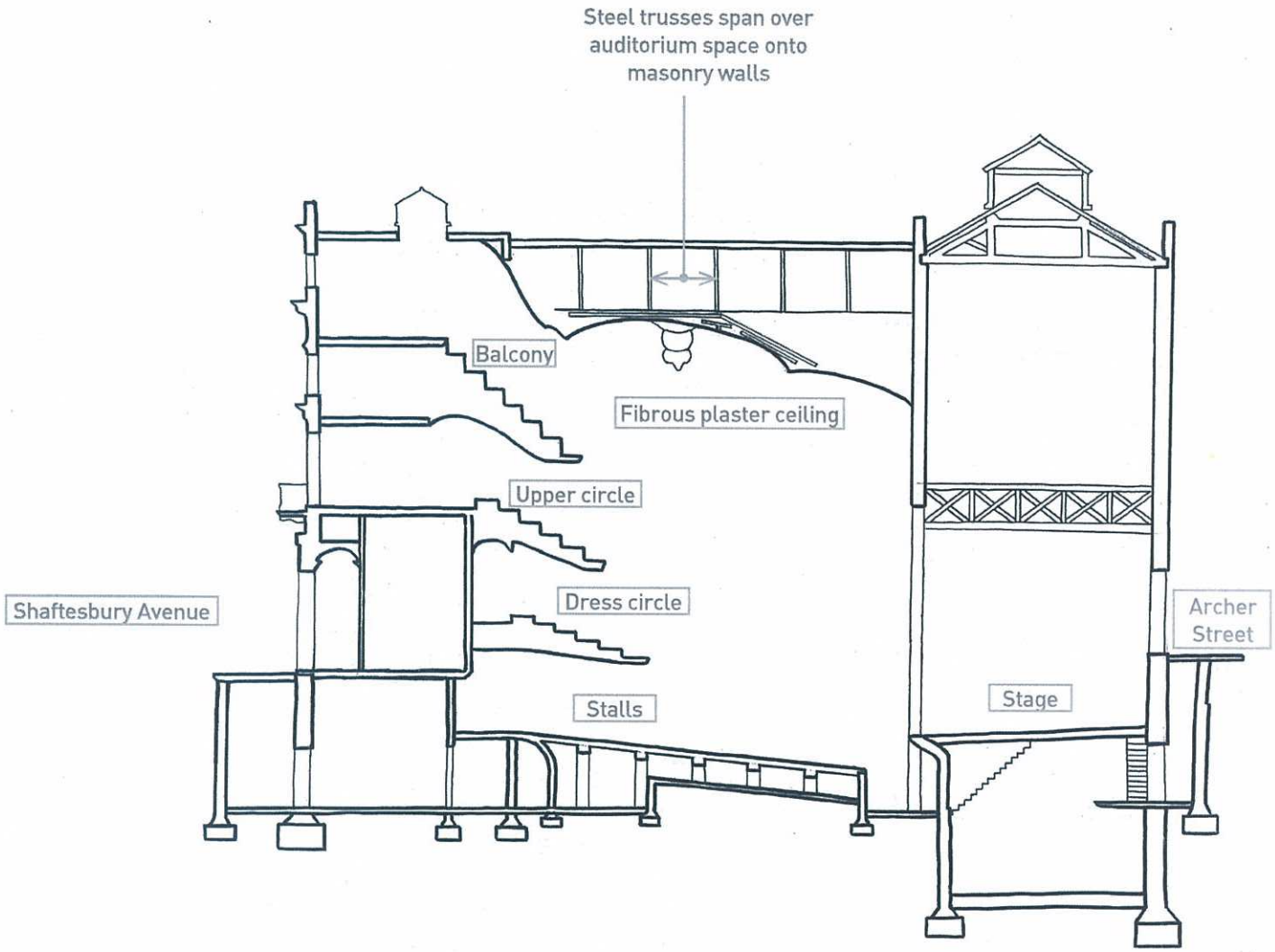


This copy shows the entry on 30-Dec-2013 at 02:25:13.

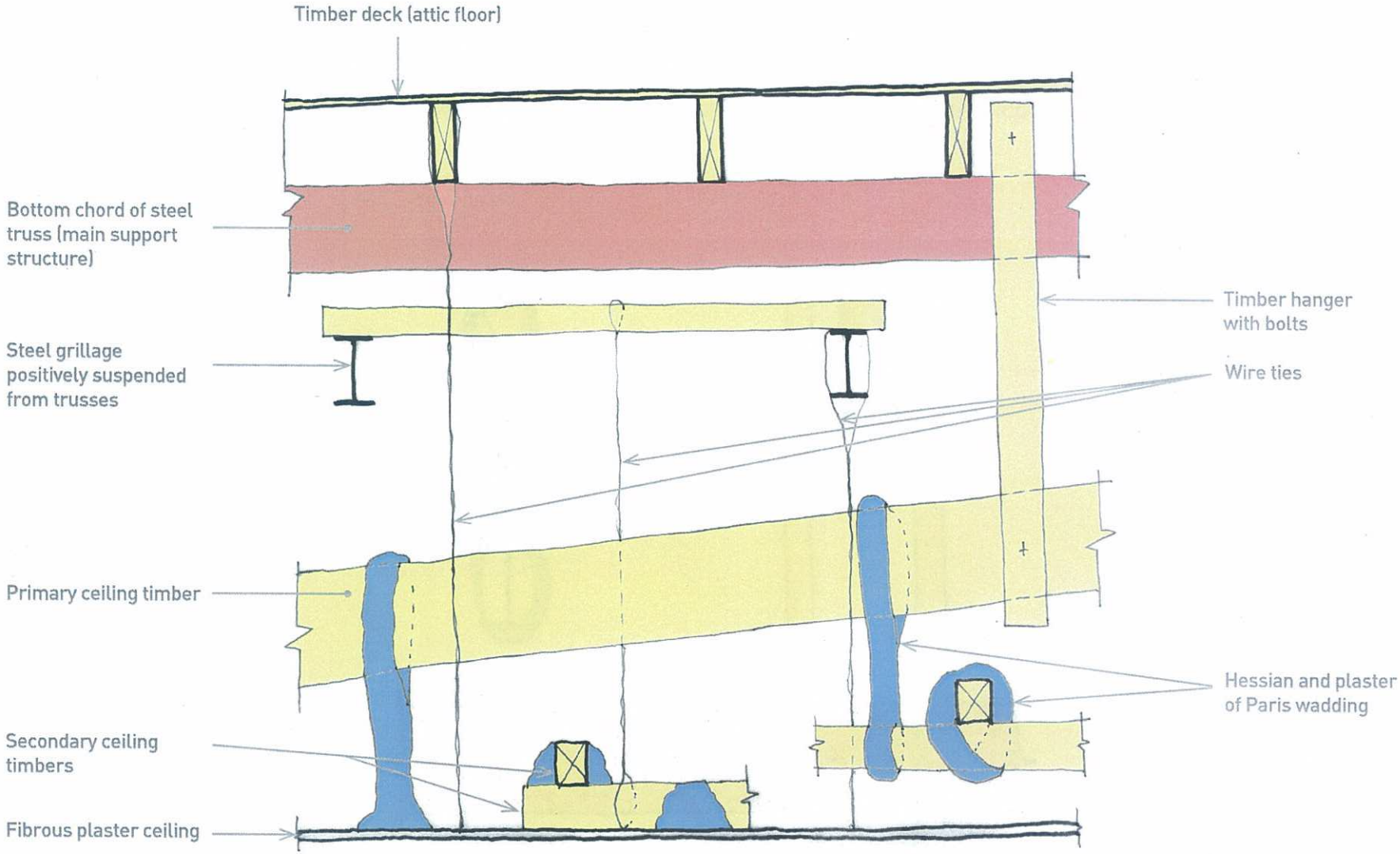
Appendix B
Sketches of the existing ceiling construction and its supporting structure



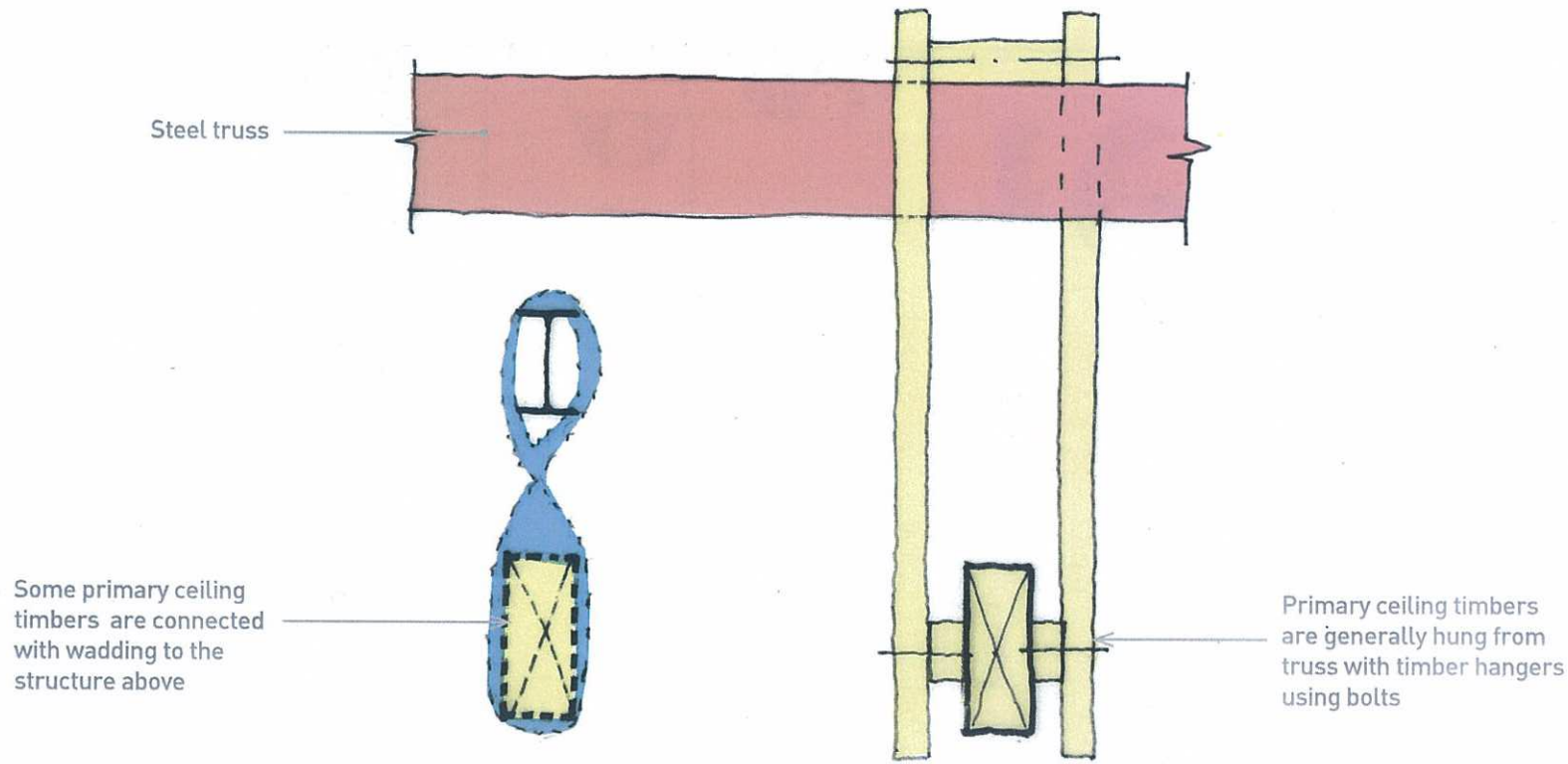
Sketch 1: Overall "short" cross-section section through the auditorium space of the Apollo Theatre



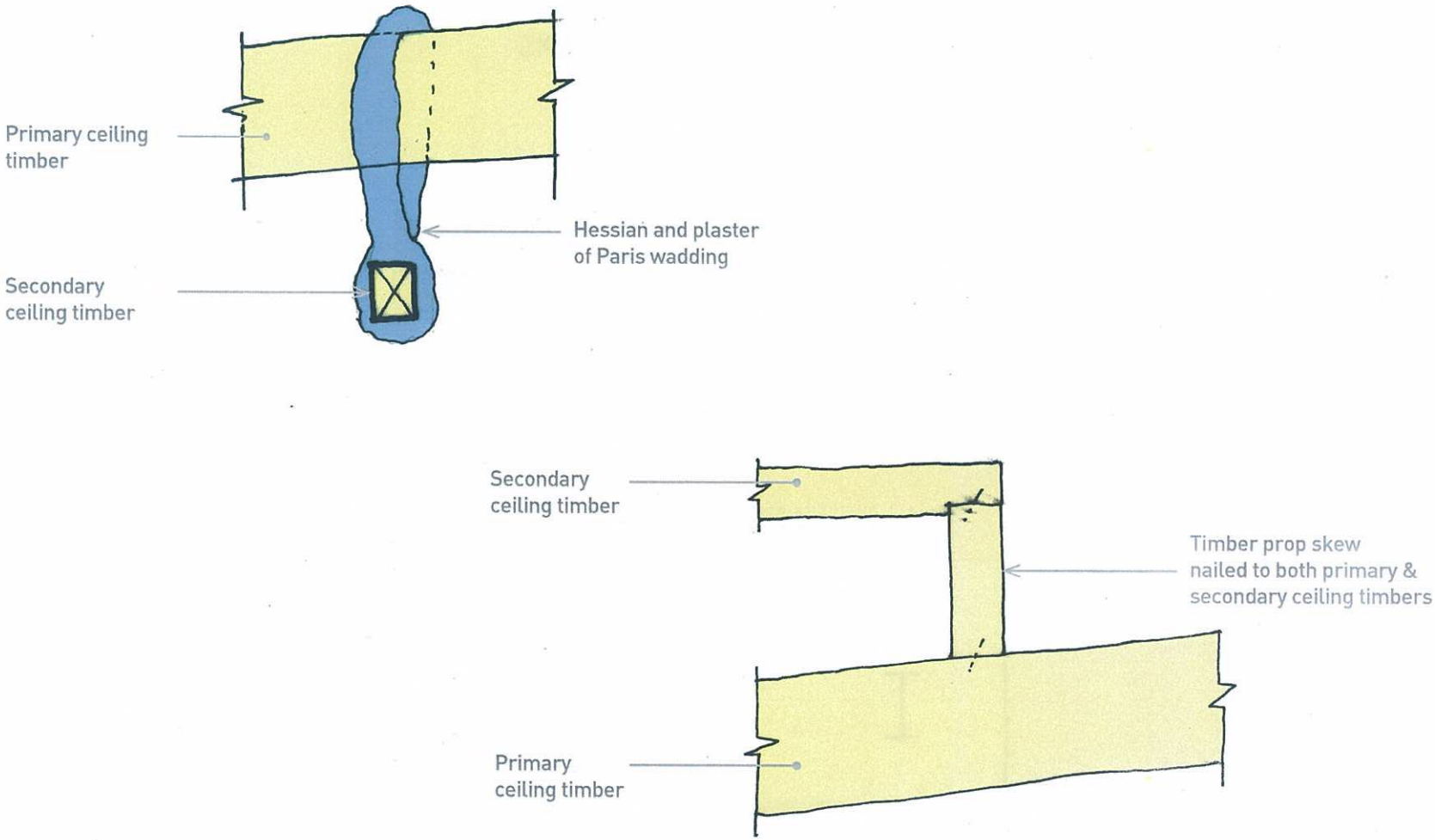
Sketch 2: Overall "long" cross-section through the auditorium space of the Apollo Theatre



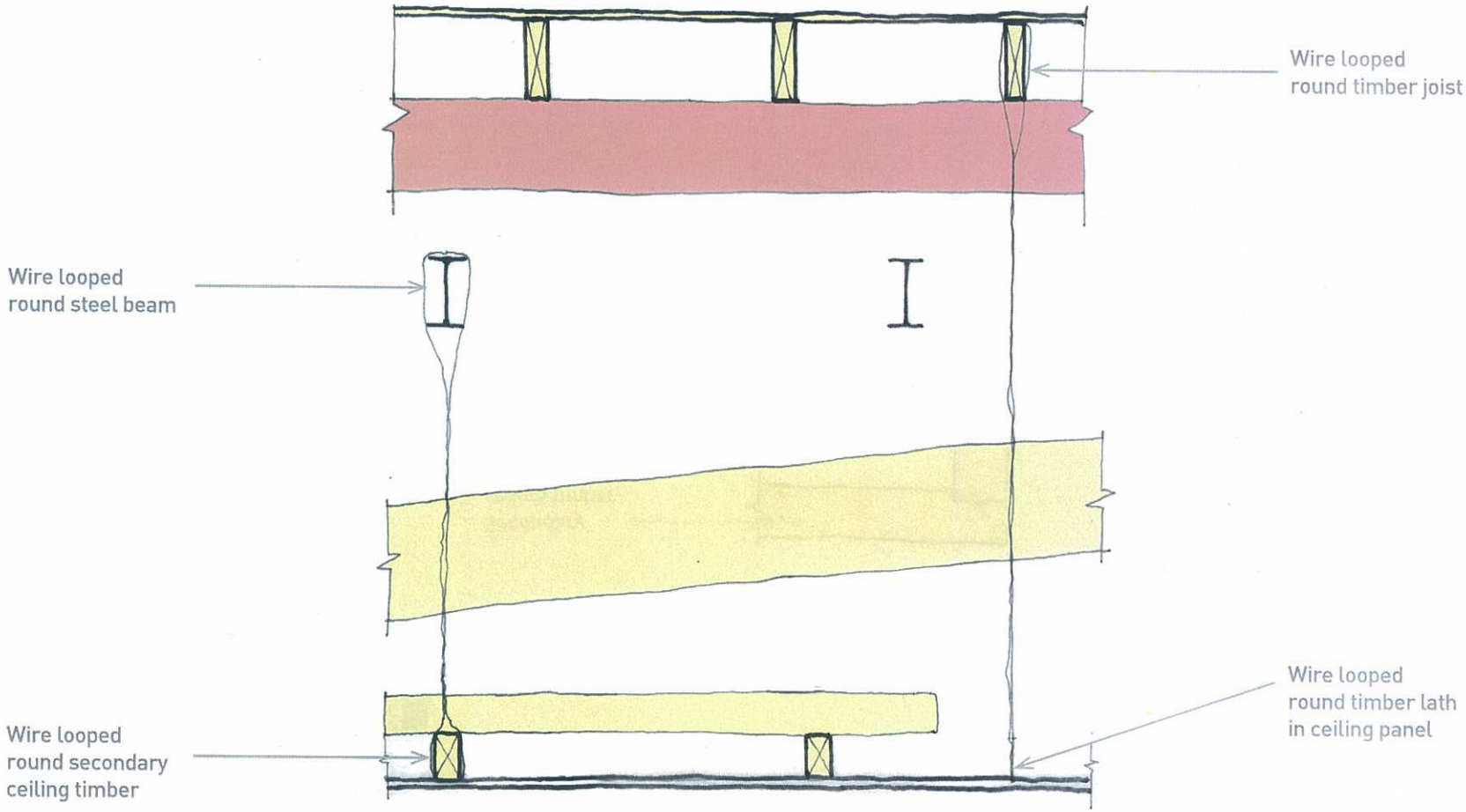
Sketch 3: Indicative section showing ceiling construction and supporting structure



Sketch 4: Typical primary ceiling timber/ main structure connection



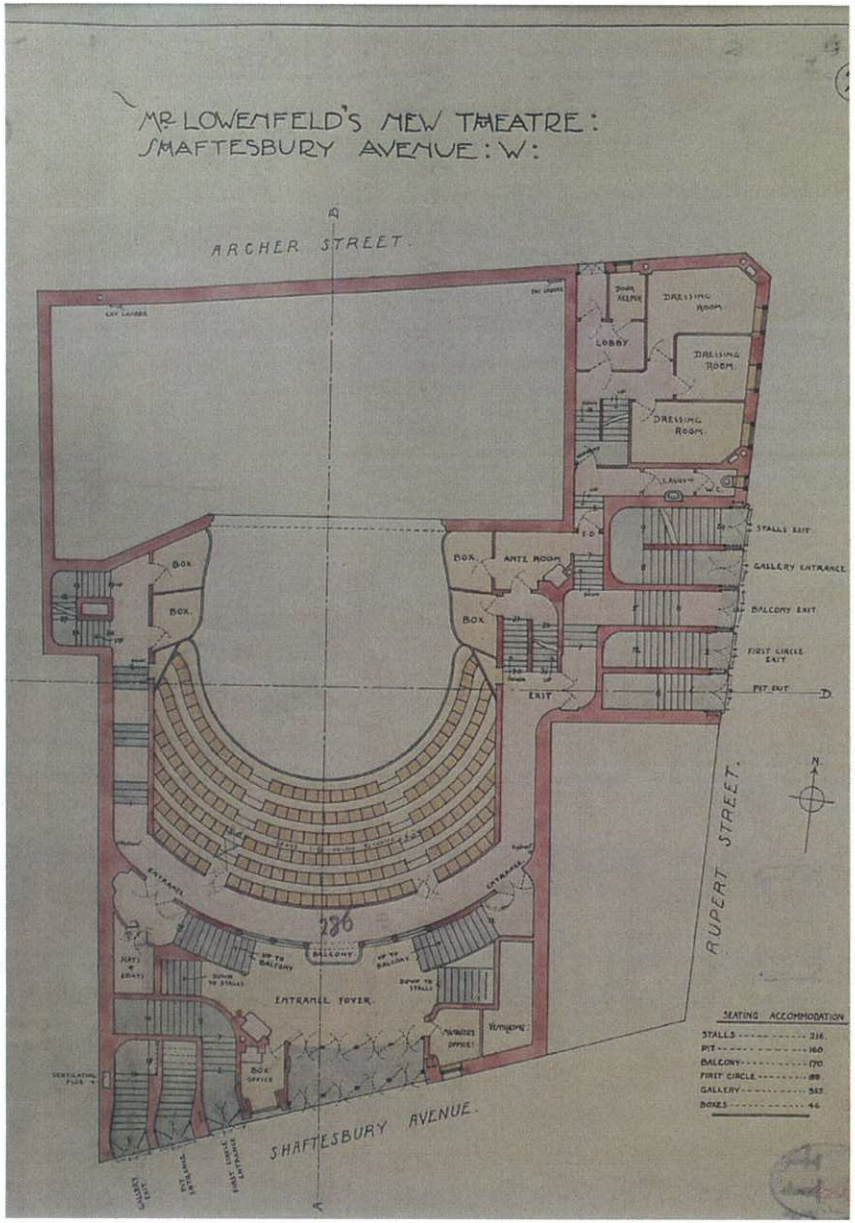
Sketch 5: Typical primary/secondary ceiling timber connections

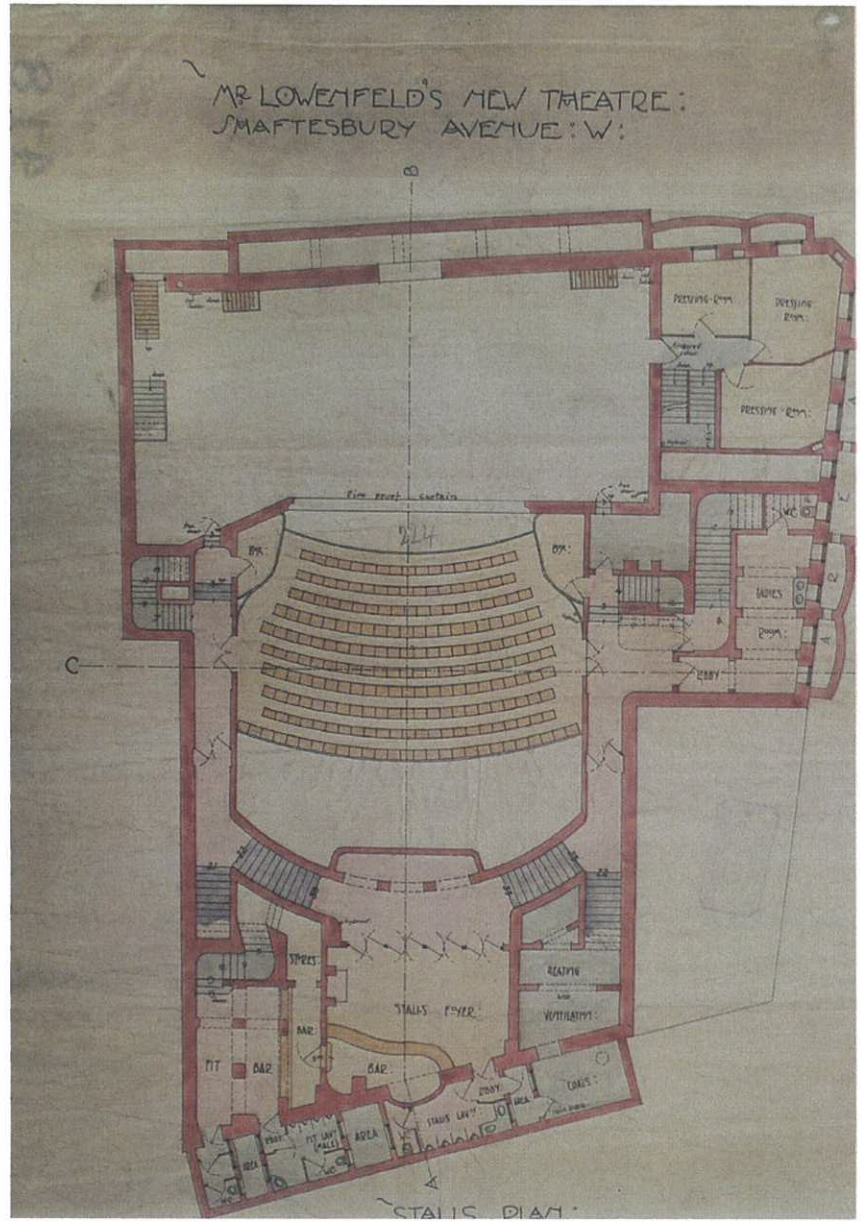


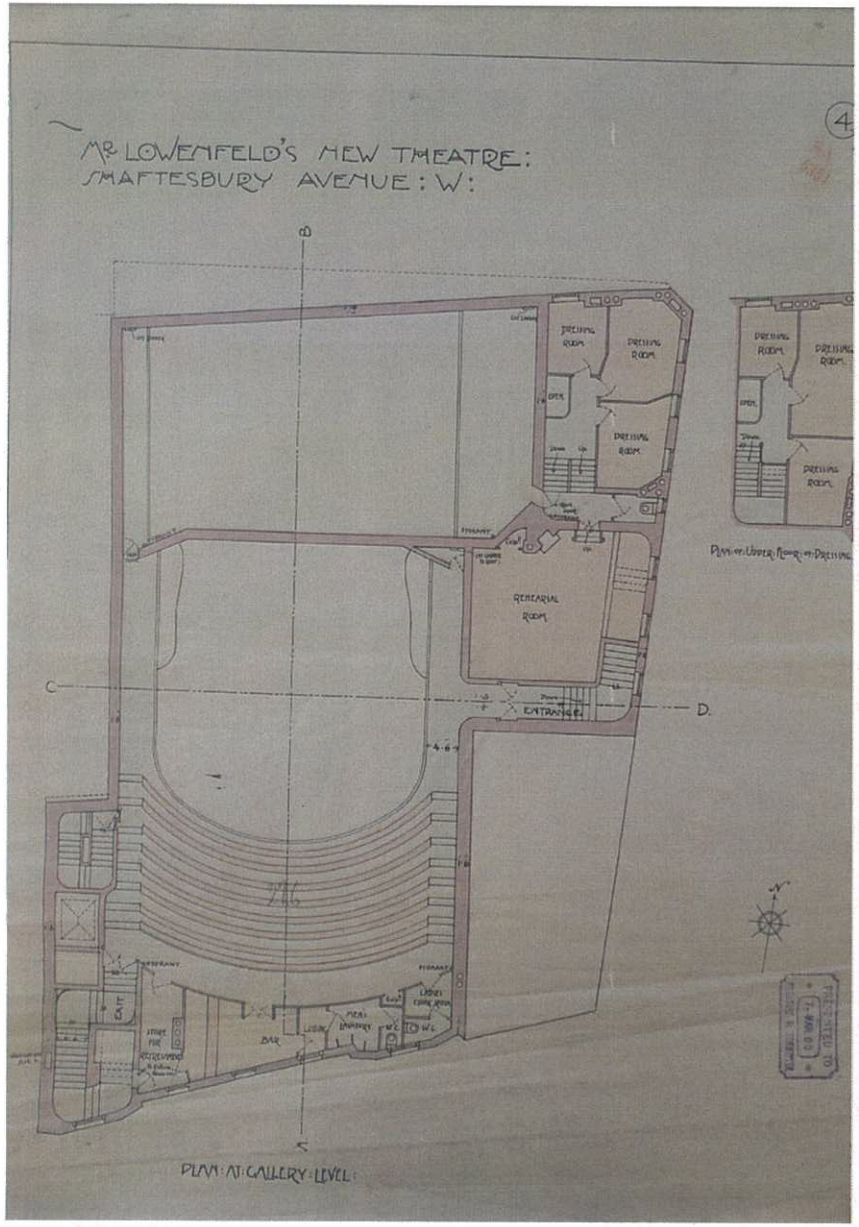
Sketch 6: Typical wire fixings

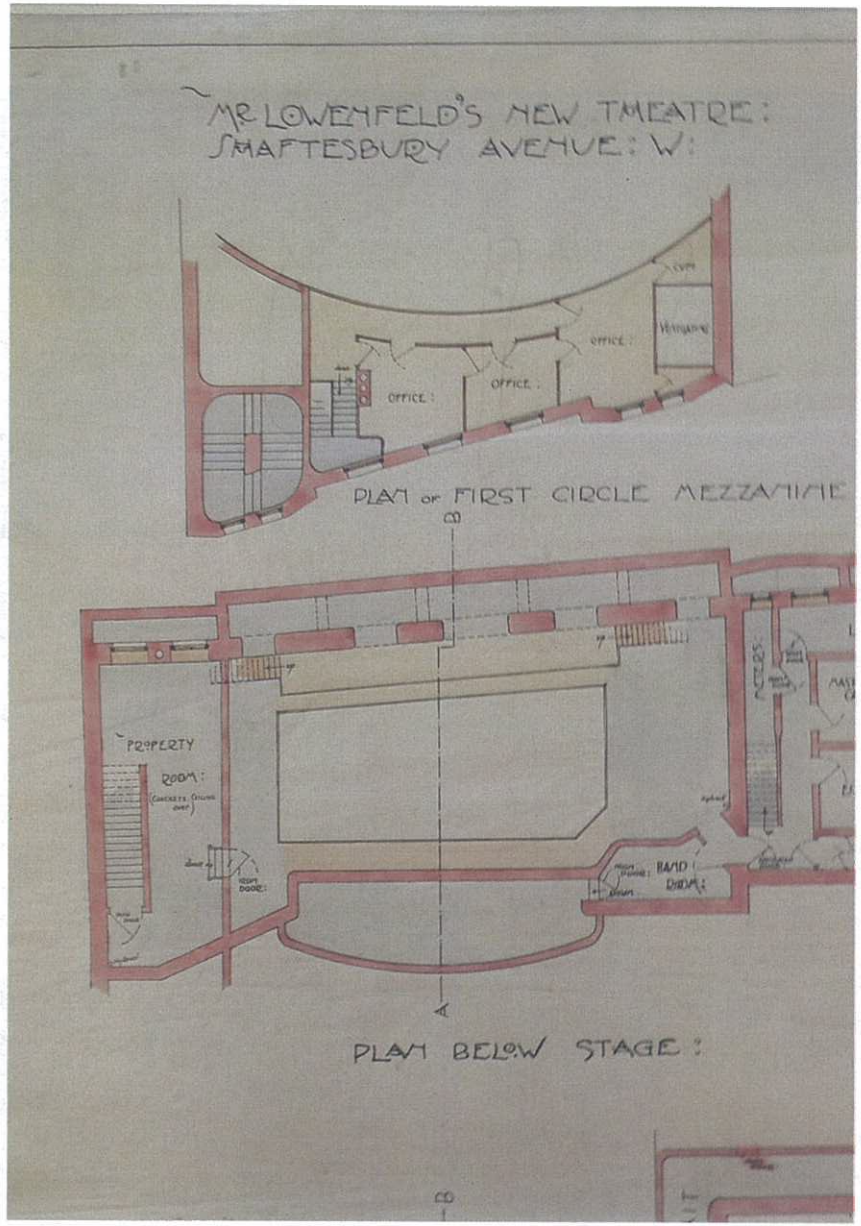
APPENDIX C – REDACTED

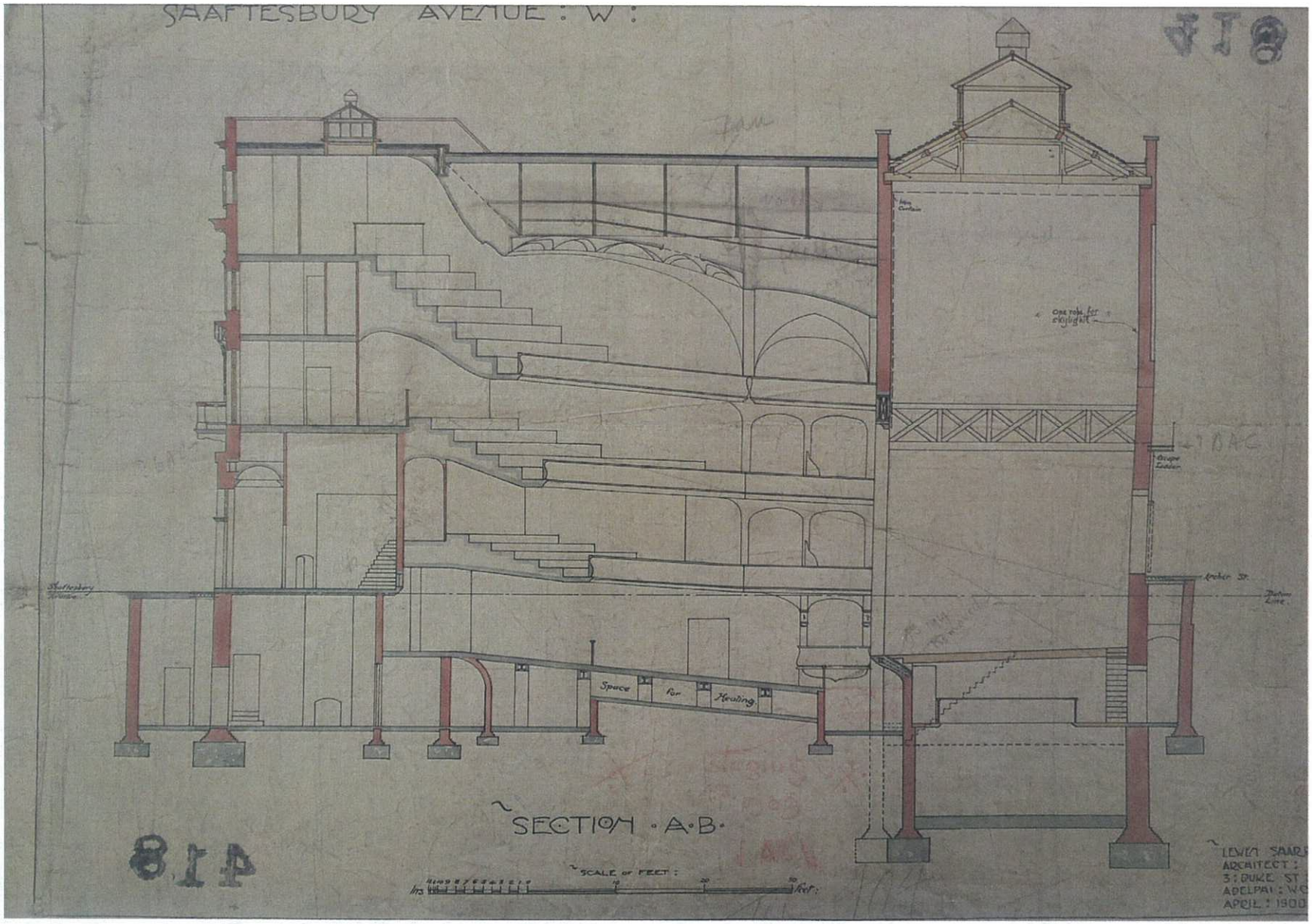
Appendix D
Archive drawings of the Apollo Theatre retrieved from the London Metropolitan Archive

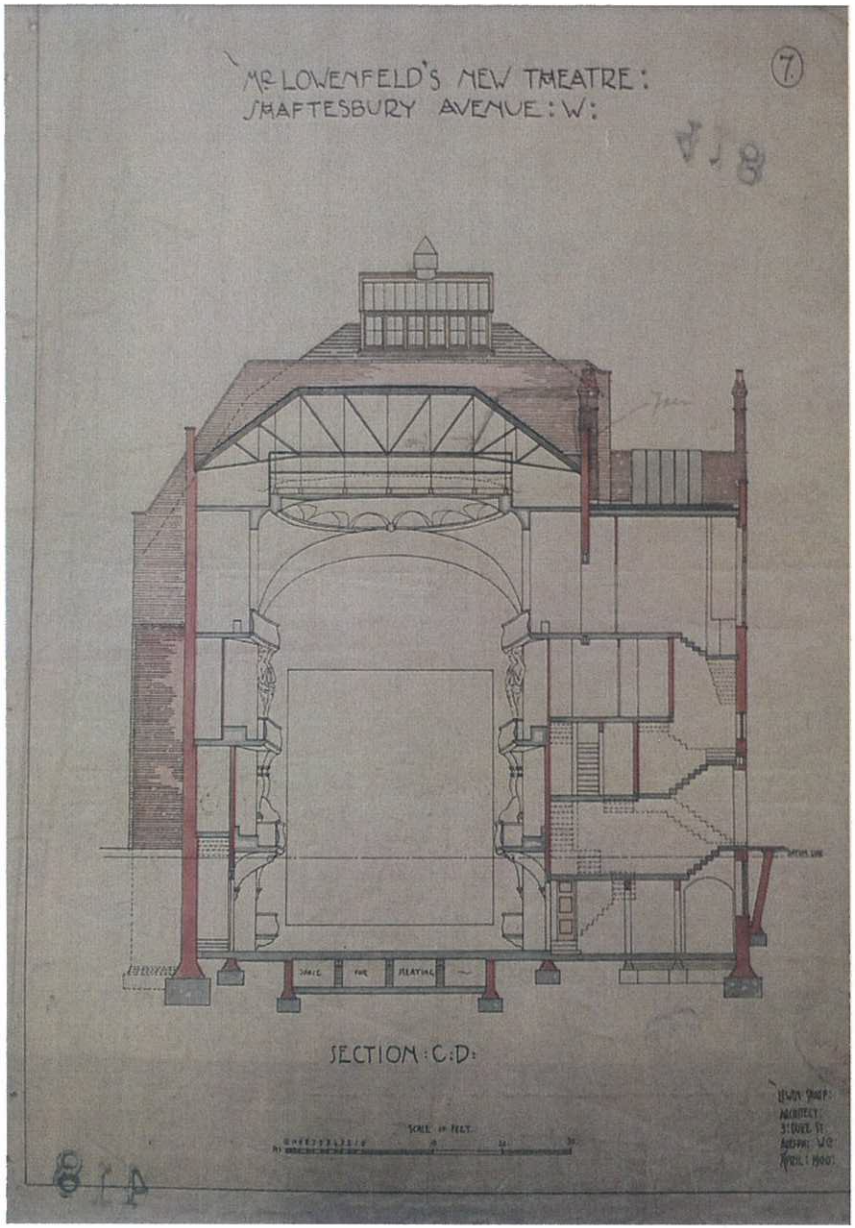

MR LOWENFELD'S NEW THEATRE:
SHAFTESBURY AVENUE: W:
ARCHER STREET.
RUPERT STREET.
SHAFTESBURY AVENUE.
DRESSING ROOM
LOBBY
ANTE ROOM
BOX
BALCONY
ENTRANCE FOYER.
STALLS EXIT
GALLERY ENTRANCE
BALCONY EXIT
FIRST CIRCLE EXIT
PIT EXIT
EXIT
SEATING ACCOMMODATION
STALLS ---- 314.
PIT ---- 160.
BALCONY ---- 170.
FIRST CIRCLE ---- 88.
GALLERY ---- 563.
BOXES ---- 46.

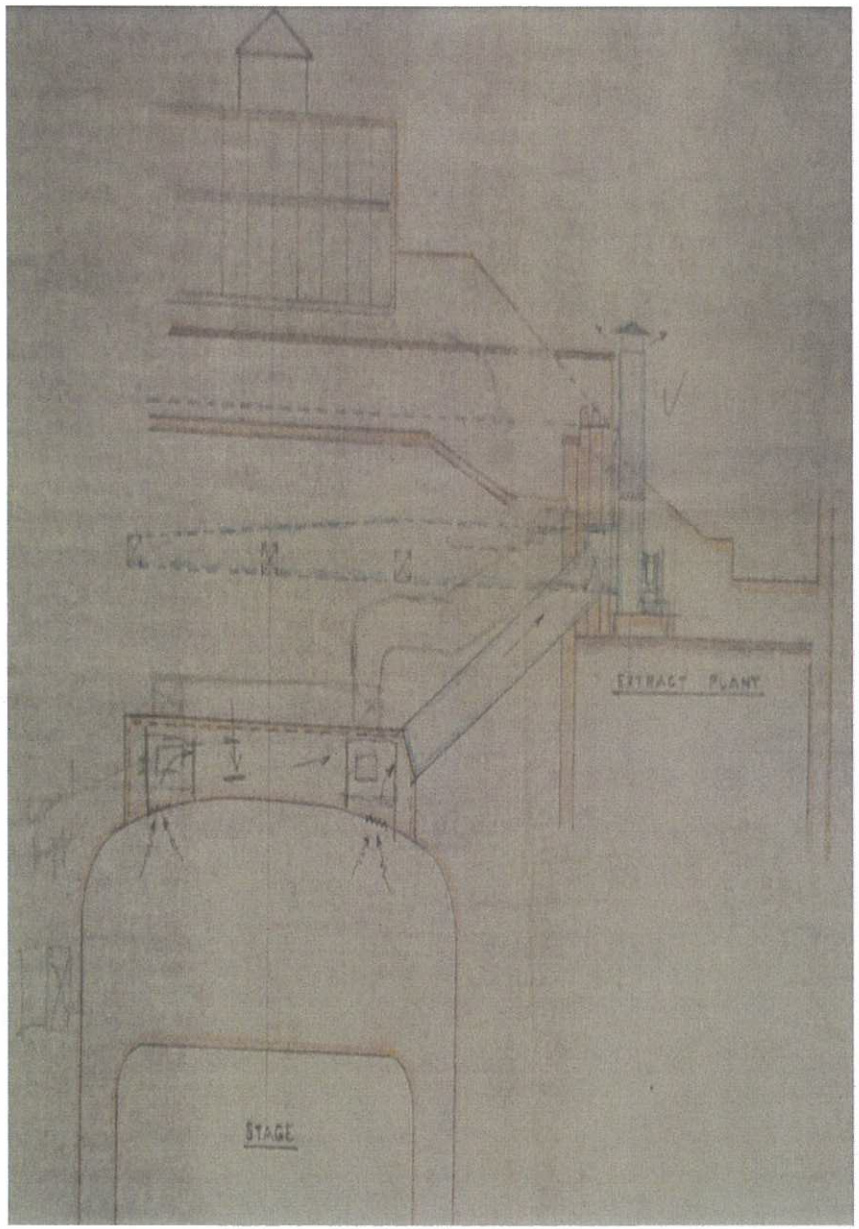

MR LOWENFELD'S NEW THEATRE:
SHAFTESBURY AVENUE: W:
STALLS FOYER
BAR
PIT
STALLS PLAN.


MR LOWENFELD'S NEW THEATRE:
SHAFTESBURY AVENUE: W:
4
DRESSING ROOM
REHEARSAL ROOM
ENTRANCE
PLAN OF UPPER FLOOR OF DRESSING
PLAN AT GALLERY LEVEL


MR LOWENFELD'S NEW THEATRE:
SHAFTESBURY AVENUE: W:
OFFICE
PLAN OF FIRST CIRCLE MEZZANINE
PROPERTY ROOM
PLAN BELOW STAGE


SHAFTESBURY AVENUE : W :
Space for Heating
SECTION · A·B·
SCALE OF FEET :


MR LOWENFELD'S NEW THEATRE:
SHAFTESBURY AVENUE: W:
7
SECTION: C:D:


EXHAUST PLANT
STAGE