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Published description of lauded buildings can include a degree of 'rhetorical editing', suppressing inconvenient truths about a building's eventual physical manifestation to suit a clear narrative.

Structural reality and architectural editing: the four invisible columns of the Sydney Opera House

Paolo Tombesi, Paolo Stracchi and Luciano Cardellicchio

The cost, the length of time it is taking to complete, the use to which the building will be put and so on have been discussed almost ad nauseam. *As a consequence, the challenge, the excitement and the technical problems encountered in what must be one of the most complex structures ever built have become obscured.*

Ove Arup and Jack Zunz, 'Sydney Opera House'.[1]

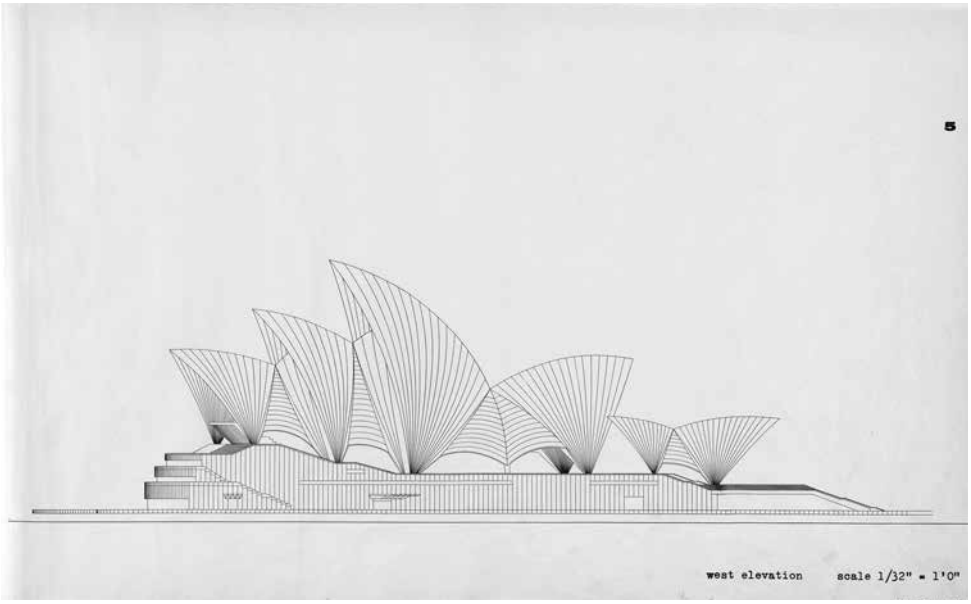
The more one studies the totalising images and narratives, the more one discovers parts of the architecture, the publication, or the history that have escaped or slipped the grip of those who so resolutely frame and present them. Indeed, the wonderful thing about architecture is how it so easily escapes the people who produce it.

Mark Wigley, 'Whatever Happened to Total Design?'.[2]

In modern architectural debate, buildings are made by their description in the literature as much as they are defined by the reality of their construction. With printing able to document project achievements and to reach a vast public so efficiently, the record of construction becomes somehow a function of its representation. But is there a difference between history and storytelling, or the construction of a building and the construction of its image? Does the primacy of curated communication over direct experience require vigilance on the side of building scholars?

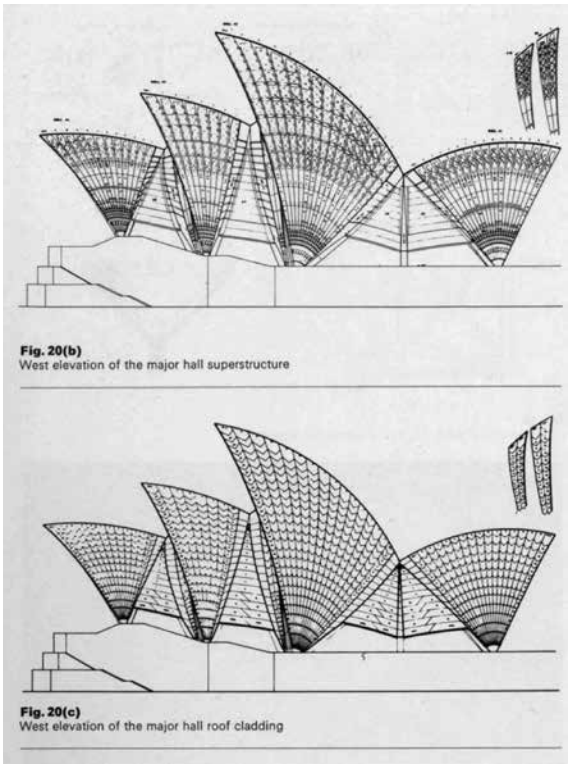
The structure of the roof sails of the Sydney Opera House (SOH) *[1]* provides an interesting case in point. The subject of a deep rhetorical construction, it has

1 Sydney Opera House from Circular Quay.



2 SOH Site Plan and West Elevation, Yellow Book, Jørn Utzon, 1962.

3 SOH West Elevation, Arup, 1962.



been portrayed in the copious literature of the last fifty years as the material result of a pure geometric concept centred around spherical surfaces, enabling arches of varying length to be cast in a common mould, and a number of arch segments of common length all departing from a fan-like base to be placed adjacent to one another to form a spherical section.[3] As the very description on the official website of the SOH recites:

> *By any standard it was a beautiful solution to crucial problems: it elevated the architecture beyond a mere style – in this case that of shells into a more permanent idea, one inherent in the universal geometry of the sphere. It was also a timeless expression of the fusion between design and engineering.*[4]

There is, however, a relatively small glitch in this celebratory description – that of a column (one of a set of four), appearing in the photographs of the main shells under construction, which contributes to the stability of the arch itself by turning its spring into a strut-like structure. Only referred to in passing in one book of the many published on the Sydney masterpiece, this discrete element questions the purity of the solution, at least as crystallised in the hagiography of the building. The columns were erected during Stage II (1963–7), at a time when the building's conceiver Jørn Utzon was still officially in control of the project, and thus with his alleged consent. While the columns do not seem to appear in the architectural or engineering narratives of the building, they are very present in its structural documents from 1963. Does their inclusion 'in the picture' alter our understanding of the building? Does it say anything about architecture and the need to elevate it by abstracting the engineering of its construction? Hitherto unexamined drawings and notes from the project help articulate the terms of this problem, the degree of contamination of the 'official' concept, and the reasons for its unfolding.

Canonical descriptions

The SOH is a composition of three roof structures that cover the two main halls and the restaurant *[2]*. There are three main elements forming each roof structure: main shells, side shells, and louvre shells. From 1957 to 1961, the main and louvre shells' geometry underwent several changes to improve their structural efficiency – from parabolic to ellipsoid, and circular. Side shells were changed too. However, the visual effect of the same was not greatly altered. Eventually, in 1961, with the development of the so-called 'spherical solution', the main shell became a curvilinear triangle (formed by ogival arches – called ribs) standing on one vertex – called pedestal. With the adoption of the spherical solution, the side shells became the primary supporting system of the main shell and louvre

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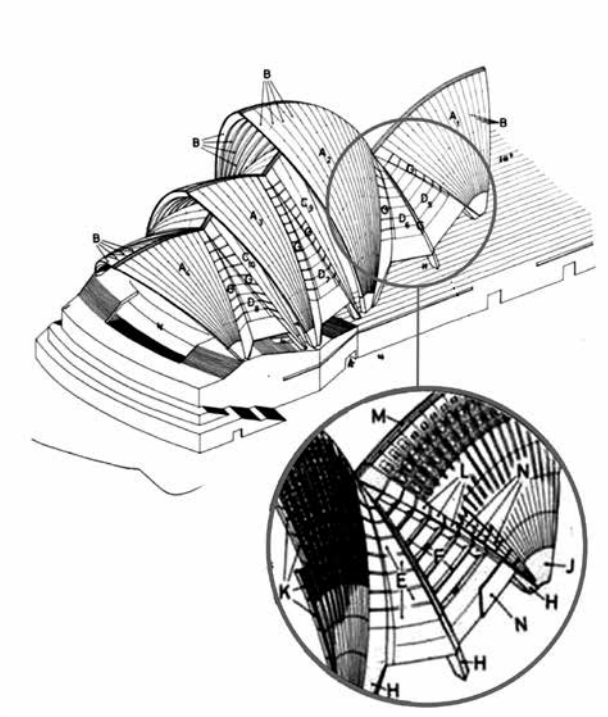

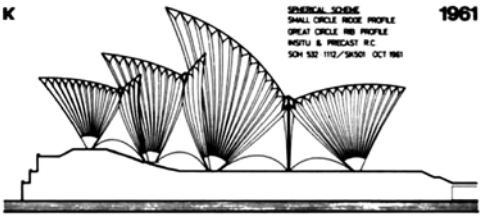

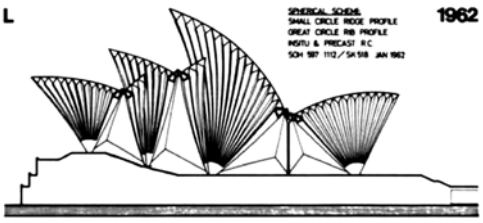

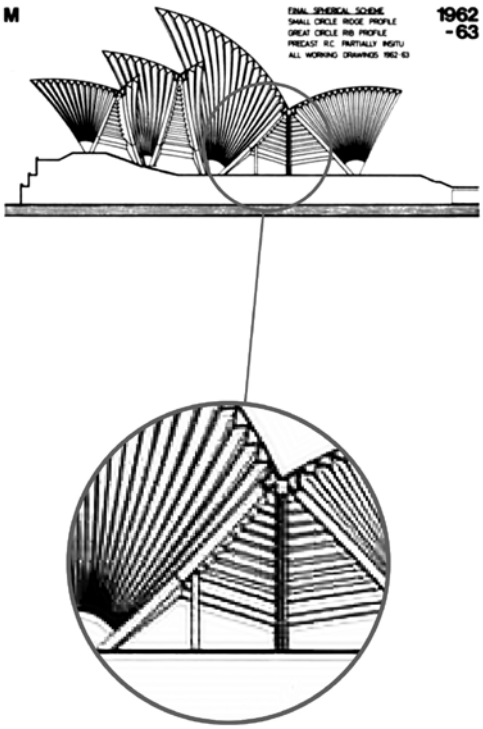

4 Top left: isometric view of the major hall shells with detail of the octopus system - H: arches spring; F: precast beams; N: cast-in-situ box beams. Top right: Spherical schemes K, L and M with detail of the supporting column of the arch spring.

shells, which indeed were radically transformed into a tripod-like structure. The tripod was named 'octopus'. Structurally, the octopus works as a self-standing tripod formed by intersecting pointed arches converging into a special piece named 'crown'. In total, there are seven supporting octopus-like tripods in the roof of the SOH: three for the roof of the main hall, three for the roof of the minor hall, and one for the restaurant. Of these, the two octopuses supporting the main shells A2 and A3 (major hall) and B2 and B3 (minor hall) feature three arches; in both the octopuses, the middle arch is

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effectively supported by a full-height wall (called stage wall), while the two lateral arches act as a supporting joint of the main and side shells. The octopus system is then completed and braced with a series of precast beams connecting the two arches, and cast-in-situ box beams that connect the footing of the octopuses *[3]*.

This, in great synthesis, is the account of the roof structure of the SOH as given by the engineers Ove Arup and Jack Zunz in the monographic issue of the Arup Journal on the building, published in October 1973.[5]

Regardless of the level of detail reported, a structural element is missing from the description. Indeed, if one looked at option M in Arup's famous diagram on the development of the geometry and structure of the sails – that is the spherical scheme from 1962–3 (p. 9, fig. 18 of the Arup report) – it would be hard not to notice a conspicuous vertical column in the profile of the side shell supporting the

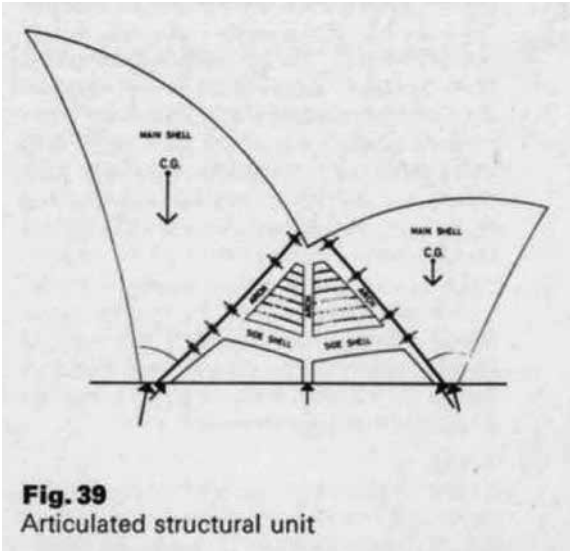
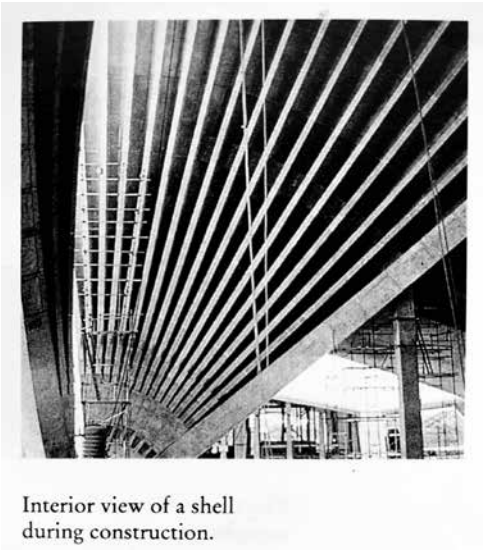


Fig. 39
Articulated structural unit



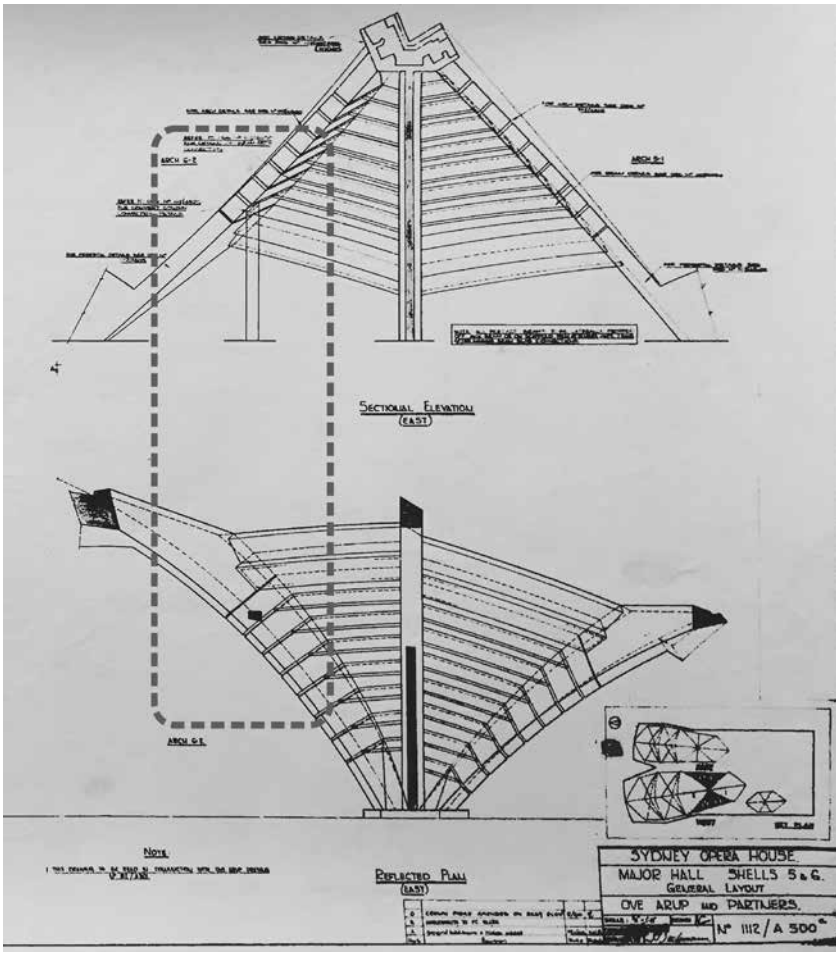
Interior view of a shell during construction.

5a, b

5a Arup's schematic drawings showing the behaviour of the side shells (with supporting column omitted). Source: *The Arup Journal* (October 1973), p. 18.

5b Detail of p. 65 of Peter Rice's book *An Engineer Imagines*, with an image of the ribcage of the roof with the column in the background.

6 Detail of Major Hall Shells 5 & 6. General layout. 1112/A500c (Arup, 1962) showing the support for the arch spring.



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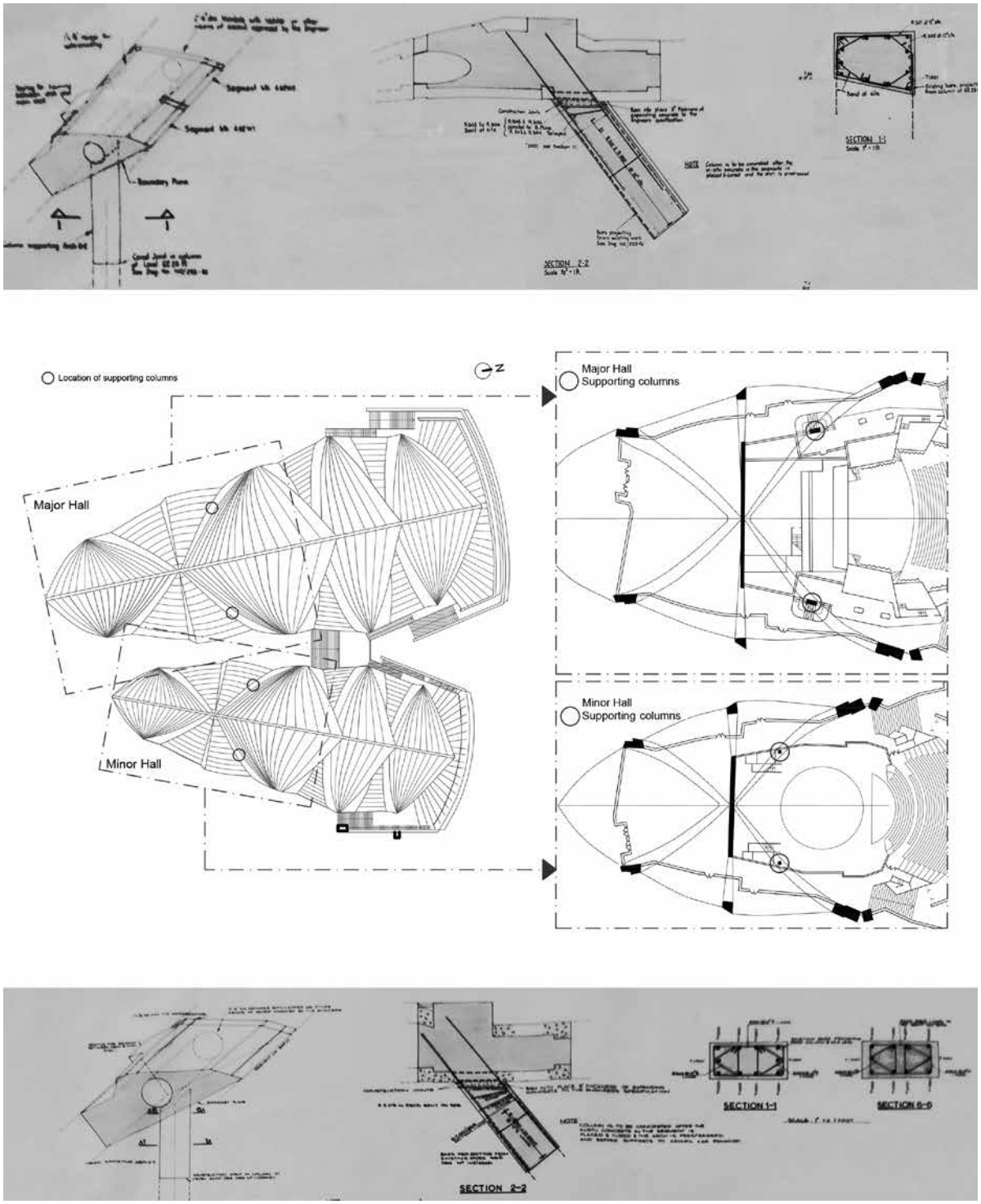

7

7 Centre: Location of the four supporting columns showing their relationship with the SOH roof and internal layout of the Main and Minor halls. Top: detail of drawing 1112/4526R (Arup, 1963) showing the supporting columns for the Major Hall. Bottom: Detail of drawing 1112/4586R (Arup, 1963) showing the supporting columns for the Minor Hall.

arch forming the octopus's structure [4]. Arup's text makes no mention of it, even within the section devoted to the 'structural analysis of the roof', which contains an explanatory diagram of the structural unit of main and side shells without the column [5a].[6] The same treatment will be provided many years later in Arup's engineer Peter Rice's autobiography *An Engineer Imagines* (1994), which reproduces the main diagram with a photographic image of the sail featuring the column, and the caption 'Interior view of a shell under construction' [5b].[7] In fact, four of these columns appeared in the eventual solution of the roofs: two in the minor hall and two in the major hall. The columns do not

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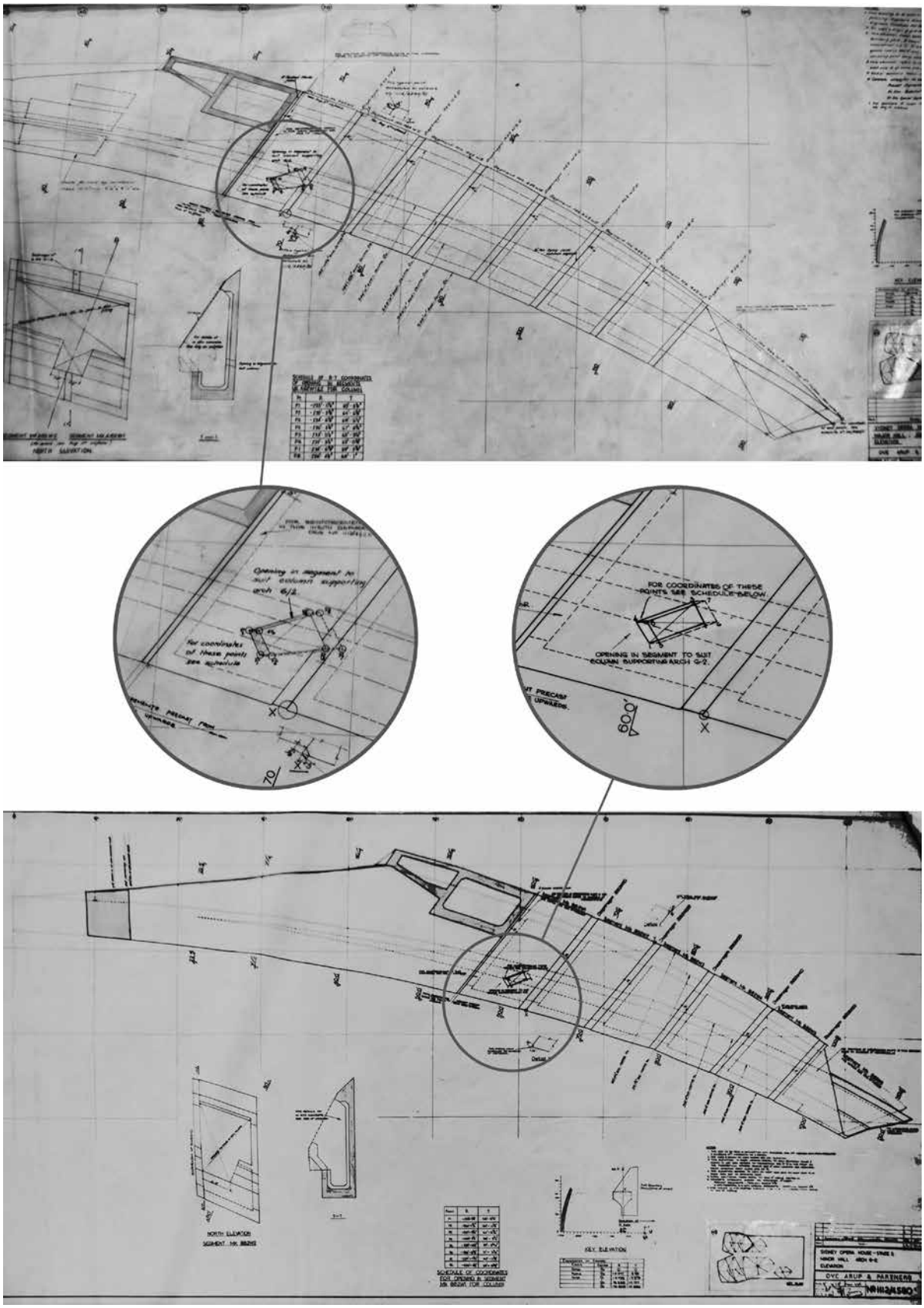

8

8 Top: Drawing 1112/4520 – Major Hall, Arch 6-2, Elevation (Arup 1963) and detail of the intersection between supporting column with the arch segment. Bottom: Drawing 1112/4580 – Minor Hall, Arch 5-2, Elevation (Arup 1963) and detail of the intersection between supporting column with the arch segment.

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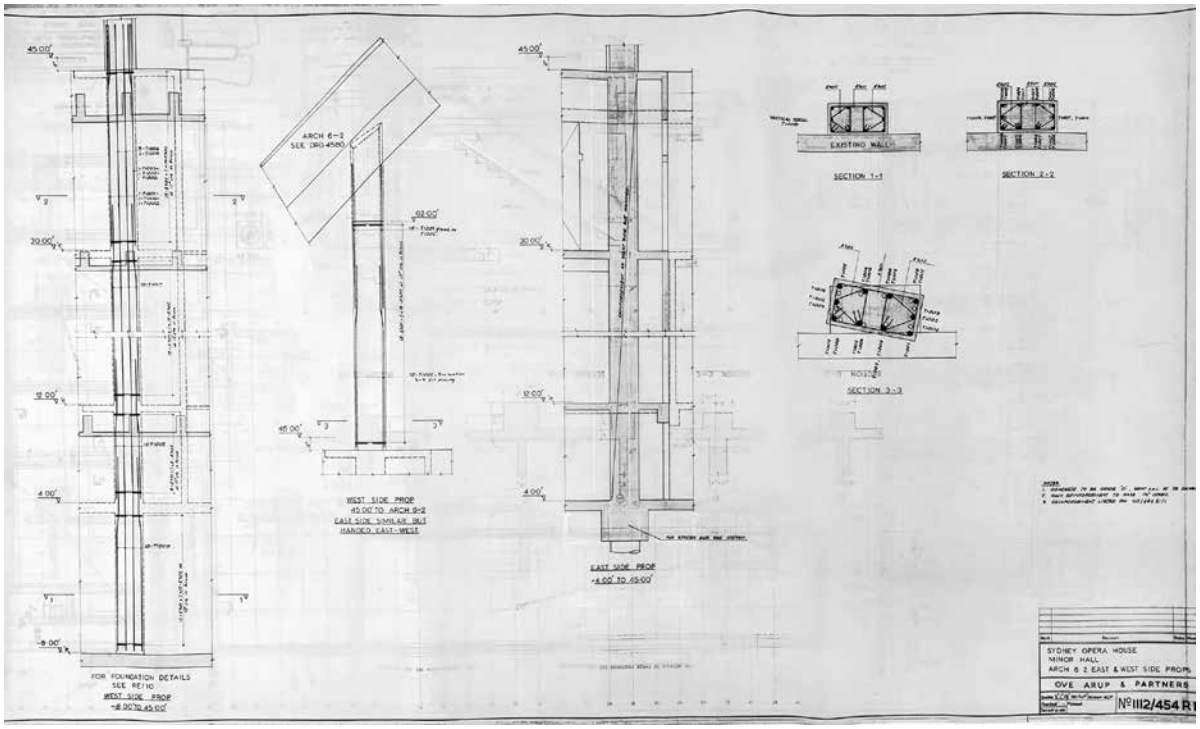

9

9 Minor Hall Arch 6 & 2 East & West Side Props, 1112/454 RI (Arup, 1963). The drawing shows the supporting column crossing the whole podium from the foundation to its connection with the arch.

feature in any of the project team minutes accessible in the project's archives. Yet, former SOH Arup's resident-engineers Ian MacKenzie and Ron Bergin recall that the side shell arch conceived in the latest iteration of the sails added an ulterior challenge to the stability of the element due to its length and relative horizontality.[8] Bergin, in particular, stated that one loading condition exceeded strength and/or deflection limits of the arches' springs. This makes it reasonable to infer that the columns were introduced to support them. Indeed, the elements become visible in the option M developed at working drawings stage as per Arup's report *[4*, top right refers*]*, which reflects the actual static condition of the tripod in preparation for construction. Structural engineering documents provide details on the columns' configuration and construction assembly.[9] The columns are located and outlined by Arup in drawing General Layout 1112/A500c (December 1962), *[6],* and detailed in two subsequent drawings – 1112/4586 and 1112/4526 (November 1963), *[7]*.

Those in the major hall feature a quadrangular irregular cross-section while the ones for the minor hall present a rectangular section. The columns were cast in situ and connected to the arches at their first hollow segments from the floor line. Such connection with the precast arch-element follows a complex procedure. First, an ad-hoc cavity would be left in the segments above the columns to suit the insertion of the projecting reinforcing bars connecting the cast-in-situ element. The bars would then be tied to a reinforcement cage pre-inserted in the hollow segment, to be infilled with concrete. Eventually, after the post-tensioning phase of the arch and before removing the temporary scaffolding, the columns were to be bonded to their arches' springs by means of a concrete collar *[8]*.[10] A further drawing – 1112/454 RI – describes the relationship between the yet-to-be-built columns of the minor hall (Stage II of construction) and the already constructed concrete podium (Stage I), *[9]*. The drawing presents the column as a towering structural element that penetrates all the podium's layers to be supported at the level of the building's foundation.

These notes bring us back to Arup's report. If the level of physical and laborious engagement between the columns and the structural fabric of the building leaves no doubt as to the element's participation in the tectonic organisation of the roof, why is it omitted in Arup's description?

Rhetorical editing

A natural answer to the question just posed is that the column stands – literally and metaphorically – in stark contrast with the rhetoric attached to the 'architecture' of the structure of the overall artefact, ie., perfect spherical shells seamlessly supported by a series of octopus-like bases. As such, it could or should be edited out, lest to contaminate the concept. After all, in the actual building it is more or less hidden – behind the separation wall that divides the public corridor from the concert halls, or encased in pillars supporting the service stairs of the auditorium's galleries. As such, its incongruous shape was only visible during construction, albeit as a potent foreground, in the magnificent shots by the Australian photographer Max Dupain *[10]*.

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10

10 Construction of the major hall with the supporting columns in the foreground.

Though concealed by their authors, the presence of those 'extra columns' did not escape the watchful eye of the critic and Australian architect Ken Woolley. In his book *Reviewing the Performance: The Design of the Sydney Opera House*, the columns are discussed as the last resort of a sculptural form that, although adopted and narrated for its structural aesthetic, defies the basic principles of its ostensible structural logic.[11] Woolley's courageous appraisal goes on to the point of placing at the centre of the review not only the design performances of the SOH but its consolidated structural-constructional narrative, victim perhaps of a hasty assertion turned fitting metaphor – the shells – which may have hampered its technical accuracy.

Whether forgotten, dismissed, or edited, it is only by looking at Arup's detailed drawings of those columns that one can understand, almost feel, the anguish inflicted by the structural resolution in object to the purity of the House's architectural image and construction storytelling. In fact, Arup's drawings betray an odd relationship between the column and the tectonic of the arch by showing no geometrical affinity between the two elements, nor hinting any explicit constructional narrative. To start with, the position of the column with respect to the arch's segment (which connects the column to the arch) changes from the major to the minor hall. In the minor hall, the columns sit almost at the barycentre of the precast segment while, in the main hall, the columns intersect the arch segments to their periphery (for this reason, the concrete infill was extended to the second hollow segment in this case). This suggests that the position of the columns was not (at least exclusively) dictated by the tectonic and geometry of the arch (or it would have, at least, intersected the centre of the first segments in both instances). Perhaps the easiest explanation is that, in their introduction, structural rationales blended with more prosaic project and internal layout priorities. In which case, the exclusion of the columns from the architectural narrative and the associated documents may be justified on clarity grounds, and the distinction between originating ideas and concrete materialisation.

Yet, a devil's advocate could posit that it is the presence of the columns that provides clarity to the project by shedding light on its dynamics beyond inevitable hagiographies. One could in fact argue that at this very time in the history of the project, while there was an intense effort in harmonising the structural and architectural design of the roof on the side of architect and engineer, some practical elements, such as the columns, were left in their raw

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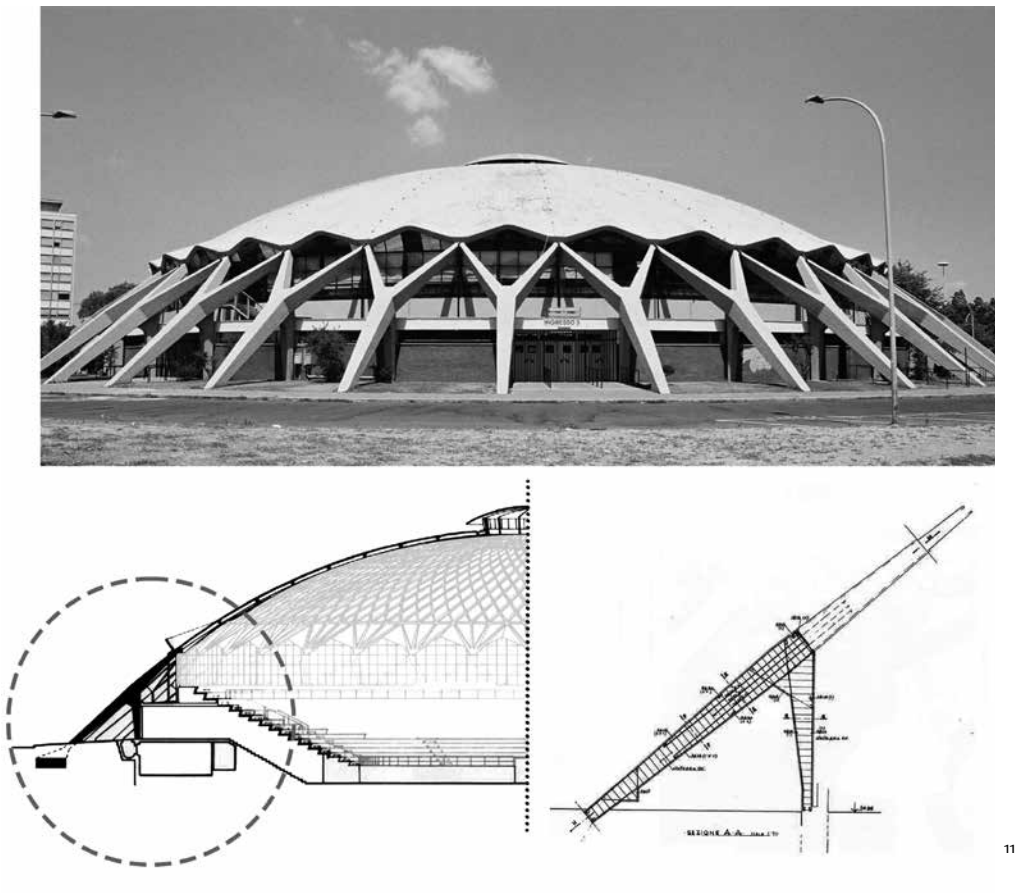
and pure functional state. This is somehow supported by seeming contradictions in Utzon's own statements (as relayed by the architecture writer Peter Murray), that one would not be able 'to separate structure from architecture when it has been finished' (1962), when he also consented to the inclusion of unrefined elements and odd relationships in the building – 'not a single pipe, dimension or type of material has up till now not been defined completely by me' (1965), eventually coming to terms with the necessity of the process – 'there has been some misunderstanding along lines that the engineer had to take over and make something that could stand up. This is not so. We are working beautifully together…' (1965).[12]

It is also worth considering that, in the 1960s and 1970s, an epoch of great emphasis on the indivisibility of the relation between structure and architecture – as shown, for example, in the works of the engineers Pier Luigi Nervi and Felix Candela – the philosophical approach of Ove Arup, the SOH's structural engineer and project manager, was not the same as that of his renowned Mediterranean colleagues. Arup's concept of 'total architecture' implied that 'all relevant design decisions have been considered together and integrated into a whole by a well organised team empowered to fix priorities.'[13] Indeed, Arup's approach was more about the design process than the intent at its base. Nor was the building's architect, Utzon, ideologically attached to formulas and/or material properties in the same way Nervi and Candela were. By all accounts, and although interested in additive geometry, Utzon was an architect devoted to the ascetic art and architecture of landscape moved by the fascination of plastic and lyrical effects.[14] By extension, the changes or the additions to the Sydney Opera House roof and structure could simply have been seen as a coherent and natural design evolution and not as a 'catastrophic consequence' of the disdaining of the most obvious laws of physics – as instead stated in 1967 by Candela in relation to the structural project of the SOH.[15] Utzon's free-form shells did not aspire to minimise material or demonstrate the potential of a structural membrane, nor did they aspire to be didactic, as in Nervi's case, where the creative process is not dissociable by static structural considerations. For example, in the Palazzetto dello Sport in Rome (1957–60), the static scheme of the Y-shaped springs of the ribs forming the dome is fully expressed in the final architectural solution. Here, all the structural sections are carefully shaped by the role they play in the static composition – with the strut supporting the dead weight of the springs included in the architectural image of the building rather than hidden and pragmatically approximated as in the SOH *[11]*.

As the architectural historian Kenneth Frampton has remarked, while the work of Nervi visually reflects the complex structural forces within it, the superstructures of the SOH were born out of a pure 'gestural' design spirit.[16]

Be that as it may, and notwithstanding the unquestionable architectural success of the



11 Top: The Palazzetto dello Sport of Rome designed by Pier Luigi Nervi (1957–60). Bottom: section of the Nervi's dome with detail of the spring featuring a full architectural integration with its supporting strut.

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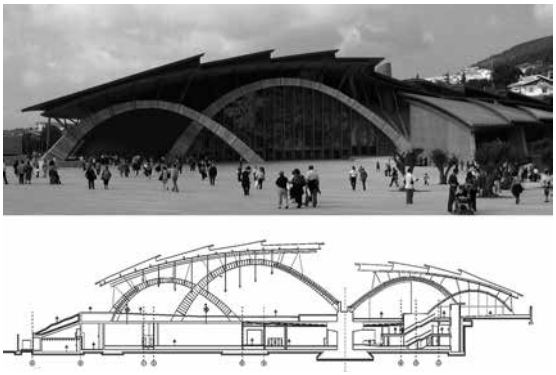
12 Left: the supporting column in the foyer of the Major Hall; Right: the supporting column in the foyer Minor Hall.

13 Top: Padre Pio Pilgrimage Church, San Giovanni Rotondo, Italy, designed by Renzo Piano Building Workshop (RPBW), 2004. Conceptual structural engineering by Peter Rice, 1991. Bottom: Cross-section showing the post-tensioned stone arches supporting the roof.



building, the presence of the column strongly resonates with the concept of 'noncorrespondence', compounded by the magnitude of the dimensions involved, through which Frampton depicts the structural incongruence of the shell roof.[17] Two primary examples are the 'noncorrespondence' imposed by Arup, whose ad-hoc quadrangular supporting columns solved the tripod-like structure but disregarded any possible architectural discourse with it; and a 'noncorrespondence' later encased by the building's Stage III (1967–73) architects in the major hall, within an elliptical section derived by the offset of the galleries' stairs profile which the column also supports, which in effect amplifies the ambiguity of the element and its very role – and from here perhaps the justification of its oblivion *[12]*.

Pragmatic history

If one accepted the insertion of the column as a practical construction/structural tactic rather than a deviation from a perfect engineering model, the appearance of a strut signalling the adoption of pragmatic solutions over further attempts at ideological integration could align with multiple interlinked rationales. A natural first would be architect Utzon's reduction of design focus and agency at this stage of the process (coinciding with the start of Stage III – the interiors) and in the design of the roof, which was basically left to engineer Arup and its commonsensical structural approach – significantly after five years of discussion and escalating political pressures combined with design cost overruns, which all demanded resolution (indeed, Mikami, the author of the book *Utzon's Sphere: Sydney Opera House – How It Was Designed and Built*, writes that the atmosphere in Arup's London office relaxed as soon as a solution for the arched tripods was found).[18]

But, even in spite of actors' contributions, does an inclusive, unedited account of the building and its engineering solutions give a better understanding of the project and its challenges? Does the recording of the distance between rhetorical structure and actual structure enable useful reconsiderations of the lessons gained in the process?

As they stand today, the four columns represent an absolutely negligible contribution to the architecture of the SOH, isolated as they are by their foreign geometry, behind walls, within partition trenches, or within functional spaces that hardly partake in the visual excitement of the sails. Their presence is more important conceptually, because it questions the structure/architecture relation mantra generated by the large majority of the literature about the project by suggesting the use of ad-hoc solutions at given locations and given times in the history of the building's construction. Hence, while they testify of both the resilience and the eventual success of the project, they also indirectly declare the partial resolution of the vaunted structure. Perhaps the value resides in this tension, and the operative lessons that can be drawn out of the experience. It is interesting, for example, to consider the columns in relation to Utzon's forming position on additive architecture at the time, which, only a few years later, would lead him to affirm that, 'when working with the additive

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14 Top: Rolex Learning Centre at EPFL campus in Lausanne by SANAA, 2011. Detail of the supporting column underneath the concrete shell-like slab. Bottom: Indian Institute of Management in Ahmedabad by Louis Khan, 1974. Detail of the deteriorating brickwork arches.

principle, one is able to avoid sinning against the right of existence of the individual components. They all manage to find expression.'[19] It would also be interesting to compare the organisation of the arches with that of the arches of the Padre Pio church (1991–2004), designed by Renzo Piano in the Southern Italian region of Apulia *[13, top]*, following an original concept by Peter Rice, who had been Arup's resident engineer in Sydney from 1962 to 1967. For the liturgical hall, Rice conceived a primary load-bearing structure formed by a series of stone arches arranged in a radial configuration. Comprising modular stone segments, welded together by means of a structural adhesive and eventually post-tensioned, the construction logic and technology of the Italian arches seem to establish a direct link with the construction of the Sydney's precast arches *[13, bottom]*.[20] In theory, being able to connect the solution adopted for the Italian project with the experiences matured in Sydney at the time would place the forgotten columns into a whole different perspective, one that would comprise 'invention' versus 'adaptation' interpretations of the elements involved as well as knowledge-transfer trajectories.

In which case, though, what sort of history should the columns' tale be part of? History of engineering, architecture, project management, construction processes? The moment one tries to imagine their location or allegiance, the columns transform into an element connecting all such histories by revealing the challenges brought up by the celebrated spherical solution, the storytelling implied in architectural thinking, the uncertainty generated by technical innovation, and the difficulty in planning construction.

Conclusion

In conclusion, Sydney's forgotten columns may punch way beyond their structural design significance, by anchoring or giving substance to otherwise difficult-to-grasp issues, not only in the life of the project that triggered their manufacture but also in the general debate about architecture and construction in complex settings. Awareness of the columns increases our potential understanding of the construction process at the opera house in Sydney with its temporal dynamics. And it does provide a concrete element to reflect on and question the various project team members' interests and engagement in its resolution.

As suggested, this may help identify bridges with other experiences carried out by the actors involved, thus outlining operative histories centred on work as opposed to traditional histories centred on ideas. Importantly, such associations would be set to clarify and bestow documentary significance on items otherwise limited in their architectural preservation value, hence sharpening building conservation management plans. The forgotten columns could indeed end up as a key element in the public's understanding of the SOH project.

Last but not least, their physical testimony reminds us of the danger, and warns us against the construction, of artificial canons that, by idealising descriptions and histories, dampen our ability to understand architectural work within its true determinants and sociotechnical challenges. The forgotten columns at Sydney are not unlike the uncelebrated column under one (false) shell of the Rolex Learning Centre at EPFL campus in Lausanne, there to prevent deflection of the slab in time but apparently invisible to official narrators of the floating building. Nor does their presence conceptually depart from that of the reinforcement bars placed inside the arched brickwork masonry of Kahn's Indian Institute of Management in Ahmedabad, and skipped by Kahn scholars until the recent catastrophic damage caused by their rusting *[14]*. Architecture's forgotten items force us to deepen our understanding of their buildings' history, oftentimes even against our will.

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Notes

1. Ove Arup and Jack Zunz, 'Sydney Opera House', *The Arup Journal* (October 1973), p. 4.
2. Mark Wigley, 'Whatever Happened to Total Design?', *Harvard Design Magazine*, No. 5 (1998), pp. 18–25.
3. See: Michael Baume, *The Sydney Opera House Affair* (Melbourne: Nelson Australia, 1967); Robert Emerson Curtis, *A Vision Takes Form; a Graphic Record of the Building of the Sydney Opera House During Stages One and Two* (Sydney: A. H. & A. W. Reed, 1967); Philip Drew and Jørn Utzon, *Sydney Opera House: Jørn Utzon, Architecture in Detail* (London: Phaidon Press, 2002); Françoise Fromonot, *Jørn Utzon: Architetto Della Sydney Opera House, Documenti di Architettura; 110* (Milano: Electa, 1998); Henry Pitt, *The House: The Dramatic Story of the Sydney Opera House and the People Who Made It* (Crows Nest, NSW: Allen & Unwin, 2018); Michael Pomeroy Smith, *Sydney Opera House: How It Was Built and Why It Is So* (Sydney: Collins, 1984); John Yeomans, *Building the Sydney Opera House* (North Sydney, NSW: Hornibrook Group, 1973).
4. 'The Spherical Solution', Sydney Opera House <https://www.sydneyoperahouse.com/our-story/sydney-opera-house-history/spherical-solution.html> [accessed 21 Nov. 2021].
5. Arup, 'Sydney Opera House', pp. 16–18.
6. Ibid., p 16.
7. Peter Rice, *An Engineer Imagines* (London: Ellipsis London, 1994), p. 65.
8. On the role of the supporting columns the authors interviewed SOH Arup's resident-engineers Ian MacKenzie and Ron Bergin on 25 February 2022.
9. In particular, see: Arup drawings: General Layout, 1112/A500c (1962); Column Supporting Arch 5&6, Major Hall, 1112/4526 (1963); Column Supporting Arch 6&2, Minor Hall, 1112/4586 (1963). Department of Public Works Sydney Opera House files (SOH files), NSW Archive and Records (NSWAR).
10. As per Arup's note in detail Arup drawings 1112/4586 (1963) and 1112/4526 (1963). SOH files, NSWAR.
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Competing interests

The authors declare none.

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