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Experiencing three-dimensional museum environments:

An investigation of the Ashmolean Museum and the Museum of Scotland

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Abstract

The relationship between the spatial organisation of museums and visitors' experience has been widely explored. However, previous studies rarely focused upon the actual use and effect of the atria on how people navigate. To understand this interaction entails answering the following research question: How exploration and movement in museums are affected by two and three-dimensional properties? This question is investigated by the comparative study of the Ashmolean Museum of Art and Archaeology in Oxford, renovated by Rick Mather Architects (2009), and the Museum of Scotland in Edinburgh, designed by Benson and Forsyth (1998). The two museums are selected as relevant cases for their spatial similarities and significant differences closely connected to the organisation of their atria. The intention is to understand whether atria account for similar or different exploration patterns in the ways users navigate in three dimensions. The comparative analysis, stemming from space use observations, space syntax methods and agent simulations, shows that significant differences in real and simulated movement result from the varying spatial positioning and character of the voids. Variability in spatial behaviour derives from the impact of the third dimension, assigning different identities and orientating capacities to the atria and the museums.

Keywords

Museum, three-dimensionality, atria, spatial cognition, navigation, space syntax, agents.

1. Introduction

The Ashmolean Museum and Benson and Forsyth's Museum of Scotland are museums of moderate size but considerable degree of complexity (Figure 1). They both consist of a number of atria of different size and configuration, interspersed inside the building layout and creating multiple visual links between galleries in two and three dimensions. Set within the historical cities' urban core, the buildings do not have enough external surface necessary in order to bring light inside the galleries. As a result, atria are used to address the compact historical sites and form of the buildings. However, a certain architectural mannerism is at work investing in layered visibility and three-dimensional connections in the interior, which might work in different ways as stimuli to exploration and navigation.

Previous space syntax studies discussing the relationship between museum layout and visitors' movement (Choi 1997; 1999; Peponis et al. 2004; Psarra 2005; Psarra et al. 2007; Tzortzi 2003, 2007), show the spatial potentials and the power of space on peoples' behaviour. However, very little focused work is available looking at the impact of three dimensionally shaped spaces on the ways in which people navigate in museums. Using spatial and configurational analysis, observational data and agent-based modelling, the paper examines how navigation patterns are configured in the two buildings. The aim is to understand the relationship between the ways in which users explore the museums and their design principles in two and three dimensions. It therefore, raises the research question: *is there an impact of atria and three-dimensional architectural design on visitors' patterns of movement and exploration?*

2. Spatial properties of the architectural layout

We begin by describing the context and the spatial properties of the two layouts. The Ashmolean Museum (situated at Beaumont Street in Oxford) was originally designed by Charles Robert Cockerell (1683), and recently renovated by Rick Mather Architects (2009). The Museum of Scotland is located in the historical area of Edinburgh and was designed by Benson and Forsyth in 1998. The entrance to the Ashmolean is found at the Cockerell building (Figure 1). The main entry to the Museum of Scotland is through a circular entrance tower, which resembles the Edinburgh castle battery, presented 'like a memory of the city's ancient gate' (MacMillan 1999, p.110). Visitors can also enter through the adjacent Royal Museum of Scotland, built by Francis Fowke (1889). The collections in both museums are organised chronologically starting from the basement upwards. In the Ashmolean, they feature under the display strategy 'Crossing Cultures, Crossing Time' which aims at highlighting interaction and influence between civilizations. The displays in the Museum of Scotland follow a chronological order, starting from the 'Beginnings' in the basement and reaching the '20th century' collections on the sixth floor.

Both museums present an intriguing three-dimensional composition with the atria punctuating their volumes and layouts (Figure 1). The Ashmolean develops in six storeys including the basement. It has a floor area of approximately 3900m² which is cut off from major external views. The Museum of Scotland has a size of approximately 3300m². It offers controlled views to the city, and similarly to the Ashmolean, is developed over six floors including the basement. The Ashmolean is organised by four major visual axes, two of which intersect at the entrance, creating a clear route structure (Figure 1, ground floor). Rick Mather's design intention was to open up the core of the museum and draw people towards the atria, enhancing three-dimensional visual interconnections. The viewing possibilities through the panoramic spaces in this building create relationships among the galleries that are often as important as the galleries themselves (Ashmolean, 2009, pg 1) (Figure 2). In the Museum of Scotland, Benson and Forsyth attempted to draw on the symbolism of the prehistoric north British brochs through the entrance tower and the use of deep shafts that, like medieval moats, separate the inner gallery volume from the outer galleries and the exterior. A triangular atrium articulates entrance to the museum, while two narrow vertical shafts, crossed by bridges, separate an inner gallery core from the peripheral galleries, reinforcing the sense of verticality and volume in the building. Moreover, the architects have the belief that architecture should not be too explicit: 'You don't see; you have to be made aware' (McKean, 2000, p.72), realised through controlled glimpses and vistas to the surrounding spaces. From the outset the designers of the two buildings seem to have used atria for opposing principles; Mather for opening up the core of the museum, Benson and Forsyth for reinforcing three-dimensional connections but also for intriguing and creating suspense.

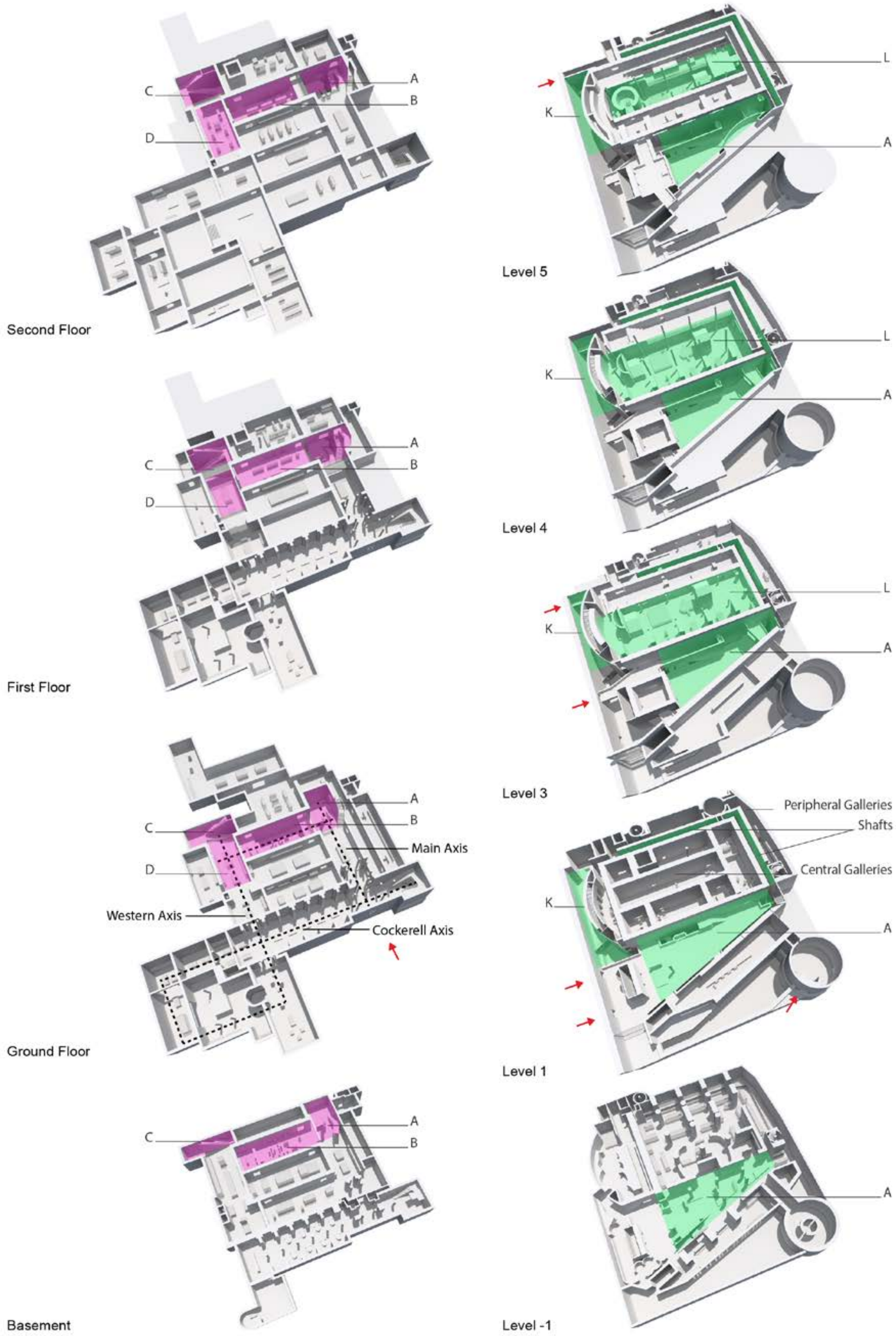


Figure 1. 3D models of the Ashmolean Museum (left) and the Museum of Scotland (right) with their entrances.

Looking at the atria as compositional components of both museums, we see that in the Ashmolean they are situated at the back part of the building, offering wide views to the galleries. The building has an additive logic in the relationship of its three-dimensional elements, connecting the old with the new extension through the use of voids. Atria A and C, both naturally lit, facilitate vertical connections through stairs throughout the height of the building, while atria B and D are double height spaces only. Atrium A is located at the northern end of the main entrance axis adjacent to atrium B; atrium B is at the centre of the museum surrounded by bridges; atrium C is located at the northern end of the western axis and atrium D is aligned with C on the western axis (Figure 1). All atria occupy 7% of the building, in both two and three dimensions (table 1). Atrium B takes up the biggest amount of space and volume (2.62%); atrium C the smallest ones (0.90%), while atrium A (1.95%) and atrium D (1.7%) are in terms of size situated between the other two. The distinct geometry and volumetric design of each atrium provides the potential for the creation of different visiting and occupation patterns (Lazaridou, 2013) linking compositional and functional aspects. These are further discussed here in comparison with the Museum of Scotland.

In the Museum of Scotland, visitors are introduced to the seven story high, top-lit Hawthornden Court (atrium A) after entering through a long entrance hall (Figure 1). This atrium features as a three-dimensional courtyard, 'a deep breather that is the focus of the entire design'[1]. Stairs and lifts are located inside this atrium connecting the ground floor with Level 3 and the basement. A central gallery volume, surrounded by the Hawthornden Court and top-lit shafts, contains a series of galleries on the ground floor (L1) and a double-height space (atrium L) on the first floor (L3). Atrium L offers views to mezzanines above, creating lower and higher spaces for display (Figure 3). The peripheral galleries are linked with the central ones through bridges revealing two narrow vertical shafts through the building. Atria A (6.4%) and L (5.8%) are different in terms of volume and two-dimensional geometry. Atrium A is trapezoidal in shape and takes 6.2%, while atrium L is rectangular and occupies 4.3% of the overall building volume. The shafts take up 3.7% in every floor in terms of horizontal footprint (table 2) and 4.36% in relation to overall volume.

Overall, there is a difference in the positioning, role and relationship between the atria in the two museums. In the Ashmolean, atria are in a complementary relationship to each other clustering in the back areas of the plan (Figure 2). Unlike the atria in the Ashmolean, in the Museum of Scotland the voids do not form an integrated vertical core but divide the museum into separate volumes linked with bridges.

In the Ashmolean the voids take up almost double the space in two dimensions compared to the Museum of Scotland (7.18% as opposed to 4.63%), illustrating that they have greater significance in the plan. However, they occupy less than half the volume (7.18%) compared to the Museum of Scotland (17%) (tables 1,2). This allows us to formulate the hypothesis that in the latter viewers acquire more expanding three-dimensional vistas, potentially getting a better overview of the internal structure. Since atria are elements of architectural expressions, we can also suggest that the greater investment on atrium volume in the Museum of Scotland reinforces the symbolic role of architecture in structuring visitors' experience and strengthening the museological message. If after all a museum is a place where culture is celebrated, the message Benson and Forsyth convey is that architecture is part and parcel of this process. In the following section we will discuss how these differences are related with the visitors' patterns of movement and navigation.

[1] It is 'the orientation space, the agora, the meeting place and the great void down onto which you get glimpses from the galleries' (McKean, 2000, p.133).

2D (m2)	Floor	Atrium A	Atrium B	Atrium C	Atrium D	SUM Atria
Basement	3900.00	55.42	113.40	21.36	-	
Ground Floor	3900.00	80.75	86.20	38.00	85.10	
First Floor	3900.00	81.24	86.20	34.82	85.10	
Second Floor	3900.00	87.46	122.75	47.93	94.70	
SUM	15600.00	304.87	408.55	142.11	264.90	1120.43
%		1.95%	2.62%	0.91%	1.70%	7.18%
3D (m3)	Volume	Atrium A	Atrium B	Atrium C	Atrium D	SUM Atria
Basement	15600.00	221.68	453.60	85.44	-	
Ground Floor	15600.00	323.00	344.80	152.00	340.40	
First Floor	15600.00	324.96	344.80	139.30	340.40	
Second Floor	15600.00	349.84	491.00	191.70	378.80	
SUM	62400.00	1219.48	1634.20	568.44	1059.60	4481.72
%		1.95%	2.62%	0.91%	1.70%	7.18%

Table 1. Area and volumetric characteristics of the atria in the Ashmolean Museum.

2D (m2)	Floor	Atrium A	Atrium K	Atrium L	Shafts	SUM Atria
Level -1	3300.00	-	-	-	80.62	
Level 1	3300.00	285.00	75.05	-	265.61	
Level 3	3300.00	256.34	99.70	320.00	116.20	
Level 4	3300.00	256.34	99.70	320.00	67.00	
Level 5	3300.00	256.34	99.70	320.00	87.50	
SUM	16500.00	1054.02	374.15	960.00	616.93	763.54
%		6.39%	2.27%	5.82%	3.74%	4.63%
3D (m3)	Volume	Atrium A	Atrium K	Atrium L	Shafts	SUM Atria
Level -1	18810.00	-	-	-	459.53	
Level 1	25410.00	2186.00	575.25	-	2036.70	
Level 3	11220.00	876.68	340.97	1094.40	397.40	
Level 4	11220.00	876.68	340.97	1094.40	229.14	
Level 5	12870.00	1004.85	390.82	1254.4	343.00	
SUM	79530.00	4944.21	1648.02	3443.20	3465.78	13501.21
%		6.22%	2.07%	4.33%	4.36%	17%

Table 2. Area and volumetric characteristics of the atria and shafts in the Museum of Scotland.

Figure 2. Views and three-dimensional section through the atria and galleries in the Ashmolean Museum.

Figure 3. Views and three-dimensional section through the atria, the shafts and galleries in the Museum of Scotland.

2. Permeability and visibility structures

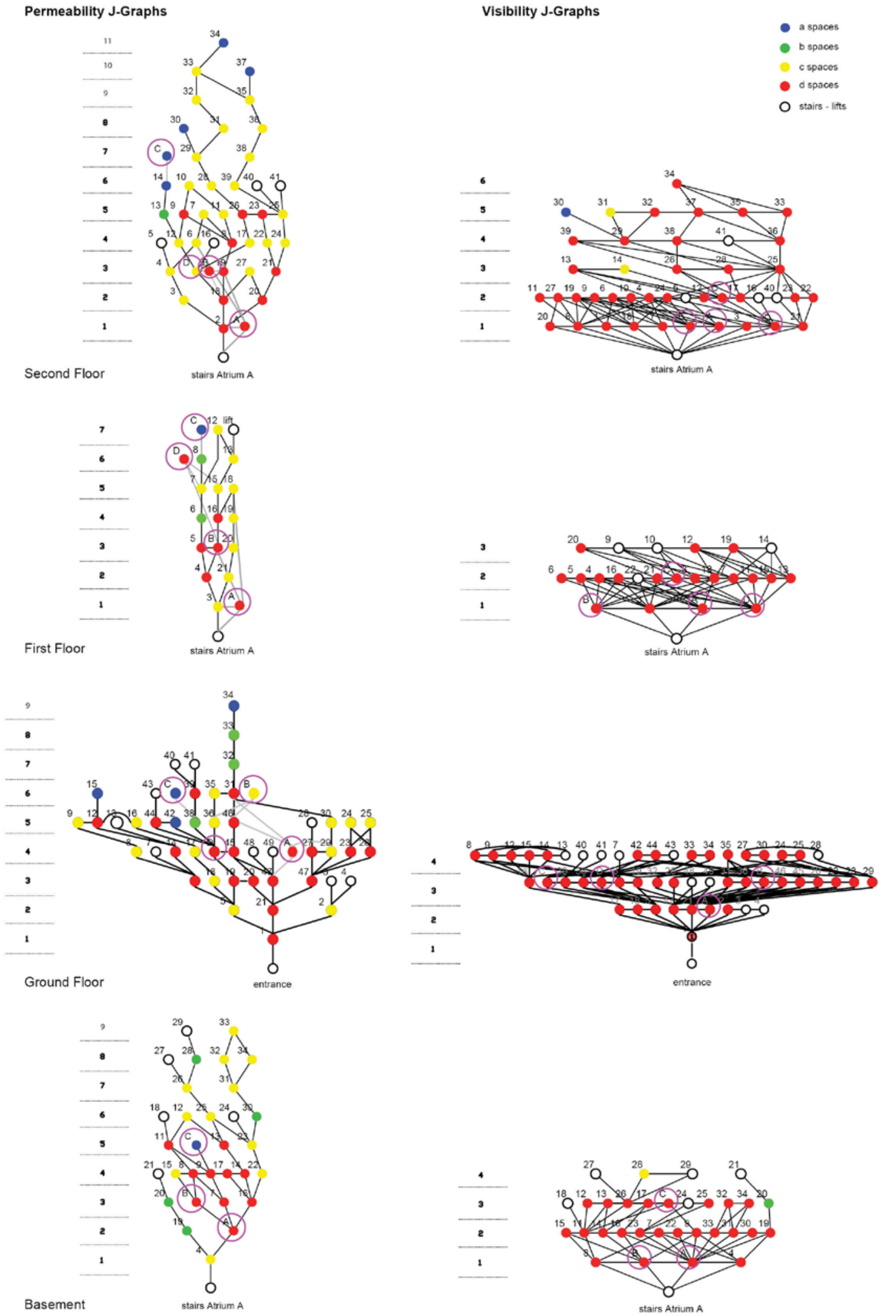
Justified graphs are used to capture the role of atria, the relationships between them, and with the rest of the spaces in the buildings (Figure 4). Half of the galleries in the Ashmolean are 'c-type spaces' and 34.5% of them are 'd-type spaces’. This means that they are embedded in circulation rings enhancing exploratory movement. All four atria are 'd-type spaces' in terms of permeability and visibility structure, apart from atrium C, which is 'a-type’ as far as accessibility is concerned. The position of the atria in the museum is such that it is likely to structure movement around and through them becoming an integral part of the two and three-dimensional circulation. In the visibility graph, the majority of spaces (96%) lie on at least two rings, being ‘d’-type of spaces[2]. The visual interconnections of the atria with each other and with other spaces in three dimensions suggests that they form a vertical core at the back part of the building which has the potential to work as a visual strong attractor (Figure 4).

Atrium A is only 4 steps deep from the entrance compared to atria B, C and D (6 steps). The probability of people appropriating atrium A as a destination and for orientation in order to change floor level is higher than choosing atrium C, which is located at the far end of the western axis. Atria B and D as double-height spaces are likely to be used for moving and viewing since they feature as exhibition spaces housing various collections (Figure 2). Visibility J-graphs are much shallower in terms of overall number of steps, compared to J-graphs of permeability (Figure 4, 17 as opposed to 36 steps from outside). The atria therefore, have the effect of making the museum much shallower, enhance vistas in three dimensions and potentially act as orientation points determining the quality of the museum experience. They seem to provide the opportunity to the visitors to integrate spatial information in three dimensions, which can aid their navigation.

Looking at the J-graphs of the Museum of Scotland we see that as with the Ashmolean most galleries lie on a ring (c-type, 32%) or at least 2 circulation rings (d-type, 36%). The rest of the galleries are equally split into 'a' (18%) and 'b type spaces' (15%). The central galleries are ‘d’ type spaces (Figure 1) and are interconnected to the peripheral route (Figure 5). In terms of visibility J-graphs, the majority of spaces turn into 'd-type spaces' (92%) reducing the overall depth levels of the graph. Likewise, all atria and shafts are 'd-type' as regards visual relations. Additionally, atrium A facilitates horizontal and vertical movement to Levels -1 and 3, interconnecting five floors and being six steps deep from the entrance. On the other hand, atrium L, situated on Level 3 and extending to three floors, enables only horizontal movement (Figures 1, 3, 5). Further, there is a hierarchical relationship between atria A and L, as atrium A (6.22%) controls movements to atrium L and the rest of the gallery spaces. Significantly larger in terms of volume, and controlling movement to the rest of the galleries, this atrium foregrounds the role of architecture in structuring experience over and above the museological functioning of the building. Atrium L (4.33%) plays also a similar role controlling movement to the inner galleries and the exhibition spaces placed at the periphery. The bridges allow penetration to the periphery of the building, yet their concrete high railings disrupt the views to the atria, leaving controlled glimpses to be discovered by the visitors.

Comparing the two museums, it turns out that most spaces are ‘c’ and ‘d-type’ spaces in both buildings in terms of permeability relations, but there is higher number of them in the Ashmolean (84.5%) than in the Museum of Scotland (68%). The latter invests more volume space on its atria and creates a hierarchy in terms of the degree of movement control they play. As we will see later through the isovist analysis, it also uses fewer interconnections among them. These differences suggest that atria in this building carry greater symbolic function than in the Ashmolean.

[2] As characterisations of spaces, ‘a’, ‘b’, ‘c’ and ‘d’ spaces derive from permeability graphs, explaining how spaces are understood through movement, these types of spaces are not always compatible with equivalent spaces in visibility J-graphs, as the later capture visibility relations that often operate across voids and cannot be experienced by occupation. However, they can still be meaningful in visualising and categorising complex interconnectivity relations among spaces.



Hillier (1996: 321) describes four topological types of spaces: a-types (links=1 dead-ends); b-types (links>1, lying on a chain or on a tree); c- types (links>1, lying on a ring) and d- types (links≥2, lying on at least 2 rings).

Figure 4. Permeability and visibility J-graphs for the Ashmolean Museum.

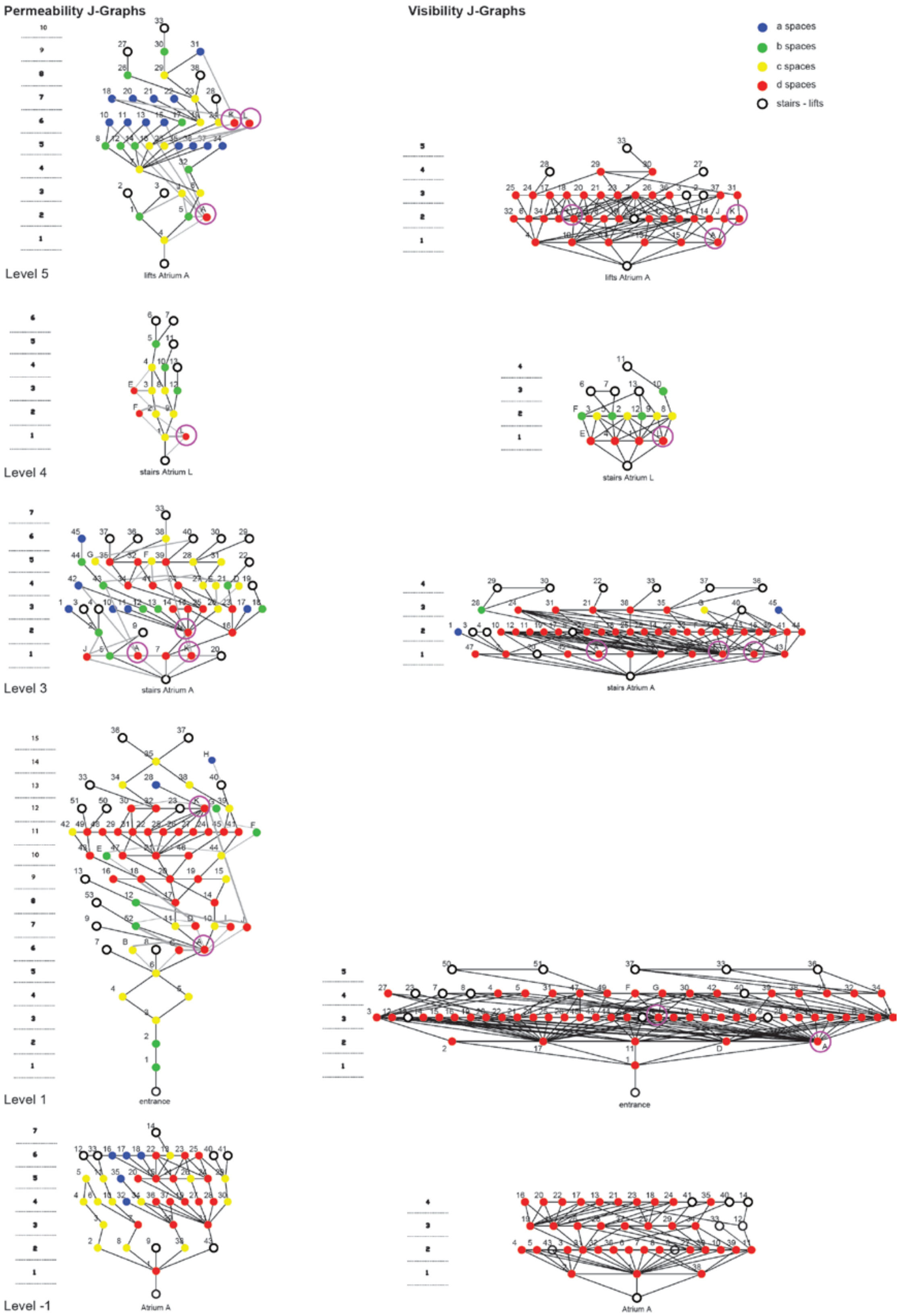


Figure 5. Permeability and visibility Justified graphs for the Museum of Scotland.

3. Isovist analysis

Looking at the characteristics of the isovists drawn from the central points of each atrium space, we see that in the Ashmolean atrium A has the biggest isovist area (9.5%) extending to the surrounding galleries (Figure 6, tables 3,5). Atrium C comes second (6.4%) with its isovist covering a sequence of successive galleries along the western axis. The double-heighted voids (B: 4.3% and D:3.1%) present smaller isovists (tables 3,5), illustrating that they act more locally than the A and C, which provide global visual awareness. Moreover, atrium C has the highest number of two-dimensional visual connections (28% of the total number of convex spaces); atrium A connects to 26% of the total number of convex spaces; finally, atria B and D connect with 19% and 14% respectively (table 3). In addition, most isovists overlap with each other constructing interconnections between the atria and strengthening their complementary role as a vertical core at the back of the building. From the visual to the conceptual level, users are exposed to an unobstructed overview of the museum's core bringing to the foreground visitors' experience.

In the Museum of Scotland, the isovist from atrium A (10.8%) covers the biggest area compared to the rest of the atria (tables 4,5). However, the visual connections to the adjacent galleries are through narrow openings, affecting the relationship between the atrium and the inner core of the museum, which contains the galleries (Figure 6). Similarly, the isovist from atrium L (7.9%) also extends to the surrounding atria and peripheral galleries through narrow glimpses on the thick walls. The relationship between atria is very controlled and there is generally very little overlap between them as opposed to the atria in the Ashmolean which have a dense pattern of visual interconnections. The building provides additional viewpoints for orientation from balconies and bridges around the atria (Figure 6). The tendency to gradually expose the three-dimensional internal structure through narrow openings and shafts can potentially create feelings of unexpectedness and surprise particularly from the the peripheral galleries, which are cut off from the rest of the building (Figure 6).

Comparing the isovist relations in both museums, we see that visual inter-connectivity between the voids in the Ashmolean creates a strong, visually unified core at the back part of the building. In contrast, the atria in the Museum of Scotland are interconnected through narrow openings meaning that the central and the peripheral galleries are experienced as separate spaces. In the Ashmolean the three-dimensional views are introduced at a later stage in one’s journey, when visitors reach the deepest parts of the building. In the Museum of Scotland they dominate the experience from the beginning. These observations strengthen the proposition made earlier that that the atria in the former have a more functional role to play than in the latter. The large atria in the Museum of Scotland would seem in the first place to aid orientation. Their visual separation for each other though, might affect their potential to assist visitors in their navigation.

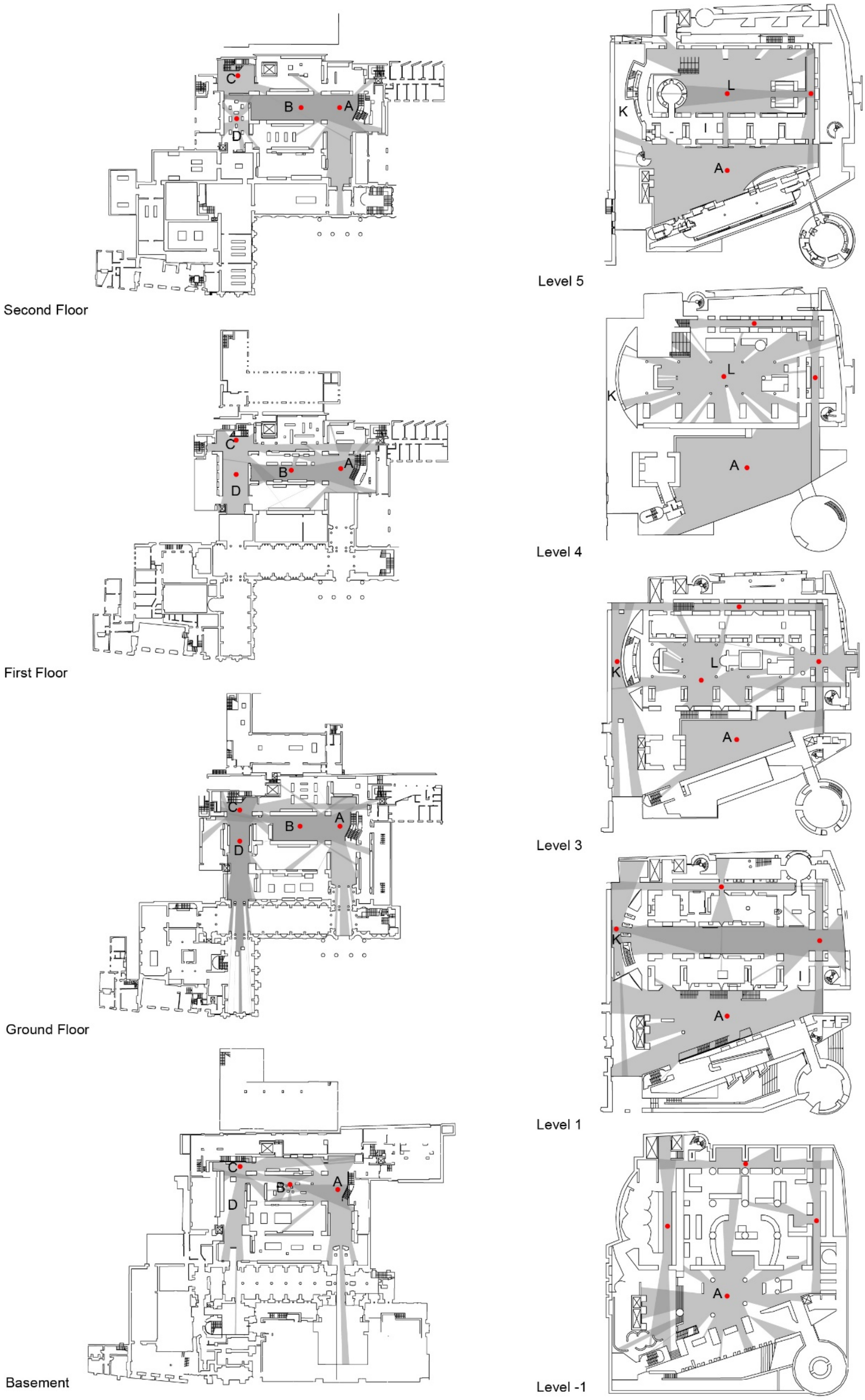


Figure 6. Isovists drawn from the central points of the atria. Ashmolean Museum (left) and Museum of Scotland (right).

	Area (m2)	Volume (m3)	J-graph (perm)	J-graph (visib)	Longest axial line (m)	Isovist Area	No_visible convex	% vis. convex
Basement								
Atrium A	55.42	221.70	d-type	d-type	47.22	374.00	9	6.4%
Atrium B	113.40	453.60	d-type	d-type	39.66	341.29	8	5.7%
Atrium C	21.36	85.44	a-type	d-type	46.53	204.58	10	7.1%
Ground Floor								
Atrium A	97.90	391.60	d-type	d-type	38.61	363.86	11	7.8%
Atrium B	86.20	344.80	c-type	d-type	39.95	202.35	8	5.7%
Atrium C	38.00	152.00	a-type	d-type	61.92	368.61	14	9.9%
Atrium D	85.10	340.40	d-type	d-type	61.92	299.50	14	9.9%
First Floor								
Atrium A	81.24	325.00	d-type	d-type	19.94	333.70	6	4.3%
Atrium C	34.82	139.30	a-type	d-type	32.72	167.70	6	4.3%
Atrium D	85.10	340.40	d-type	d-type	25.50	183.80	6	4.3%
Second Floor								
Atrium A	87.46	349.90	d-type	d-type	41.48	405.96	10	7.1%
Atrium B	122.75	491.00	d-type	d-type	46.13	126.58	11	7.8%
Atrium C	47.93	191.70	a-type	d-type	42.56	257.26	10	7.1%

Table 3. Spatial properties of the atria and their isovists in the Ashmolean Museum.

	Area (m2)	Volume (m3)	J-graph (perm)	J-graph (visib)	Longest axial line (m)	Isovist Area	No_visible convex	% vis. convex
Level -1								
atrium A	285.00	1624.50	d-type	d-type	55.50	410.56	11	6.0%
Level 1								
atrium A	285.00	2186.00	d-type	d-type	51.82	557.53	20	11.0%
atrium K	75.05	575.25	d-type	d-type	50.58	383.36	15	8.2%
Level 3								
atrium A	256.34	876.68	d-type	d-type	53.00	293.00	5	2.7%
atrium K	99.70	340.97	d-type	d-type	45.60	178.60	4	2.2%
atrium L	320.00	1094.40	d-type	d-type	51.90	385.30	15	8.2%
Level 4								
atrium L	320.00	3742.85	d-type	d-type	52.10	477.60	5	2.7%
Level 5								
atrium A	256.34	1004.85	d-type	d-type	48.30	524.50	10	5.5%
atrium K	99.70	3939.01	d-type	d-type	45.50	250.00	2	1.1%
atrium L	320.00	1254.4	d-type	d-type	30.20	433.90	13	7.1%

Table 4. Spatial properties of the atria and their centre isovists in the Museum of Scotland.

Ashmolean Museum			Museum of Scotland		
Sum Levels	Isovist Areas	%	Sum Levels	Isovist Areas	%
Atrium A	1477.52	9.5%	Atrium A	1785.59	10.8%
Atrium B	670.22	4.3%	Atrium K	811.96	4.9%
Atrium C	998.15	6.4%	Atrium L	1296.80	7.9%
Atrium D	483.30	3.1%			

Table 5. Average values and percentages of isovist areas in the Ashmolean and the Museum of Scotland.

4. Spatial analysis of the two atria museums

In this section the analysis moves from the more apparent spatial properties of the buildings to the less obvious ones, looking at their spatial configuration. Rick Mather's design intention to attract people to the back part of the building, is captured by the axial analysis, as integration is intensified around the central and back spaces of each floor (Figure 8). In terms of visibility structure, the atria become an integral part of the integration system due to their positioning. They visually unify the galleries into a dense pattern of visual interconnections (Figure 7). Particularly, atrium A attracts the highest integration values (mean VGA: 8.12) acting as the most important visual integrator in the museum (table 6). Atrium C is the second most integrated space (mean VGA: 7.23) and atria B and D present lower values similar to each other. The intelligibility levels (axial, VGA) of the layout are overall higher in terms of visibility than permeability, showing the possible influence of the atria in the ways in which people navigate.

In the Museum of Scotland, axial integration on Level 1 resembles a deformed wheel and picks up four lines connecting the entrance with the central galleries through atrium A and the galleries with themselves (Figure 7). The most integrated lines, like in the Ashmolean, run from the left to the right and from the front to the back sides of the building intersecting at regular intervals. The internal circulation system includes numerous loops intersecting with the peripheral route (Figure 5).

Looking at Visibility Graph Analysis (VGA) in the Ashmolean we see a similar pattern to the one observed in the axial analysis (Figure 8). VGA analysis in Benson and Forsyth highlights the central galleries as the most integrated spaces, (Figure 8) which are separated from the peripheral ones. The latter appear rather segregated acting as the background upon which peripheral movement is structured. However, the axial intervisibility relations between the central and peripheral galleries draw integration towards the surrounding spaces, which become part of the larger circulation system (Figure 8, Levels 4,5). Atria A and L act as orientation places at different stages in one's journey, located in strategic positions and being part of smaller and bigger circulation systems. Atrium L presents higher integration (9.00) compared to atrium A (8.19) (tables 9,10) interconnecting various galleries. The peripheral shafts show lower values, nevertheless retaining their significance in providing route possibilities by being 'd' spaces.

In general, it seems that the Ashmolean has a highly integrated visual core that includes all voids. This three-dimensional system would seem to feed into visitors' perception of space providing visual unity and continuity during their navigation. Moreover, the segregated galleries are highlighted in terms of visibility making people aware of additional route possibilities. On the other hand, the voids in the Museum of Scotland disconnect physically the internal from the peripheral galleries. However, the visibility and permeability structure establishes good levels of connections between central and peripheral locations through axial lines and narrow vistas crossing the atria. These differences between axial integration and VGA integration seem to suggest a disjunction between the linear structure of circulation which has an integrated and permeable grid-like configuration, and the visual structure of the museum which due to narrow openings and thick walls isolates the periphery from the central core of the building.

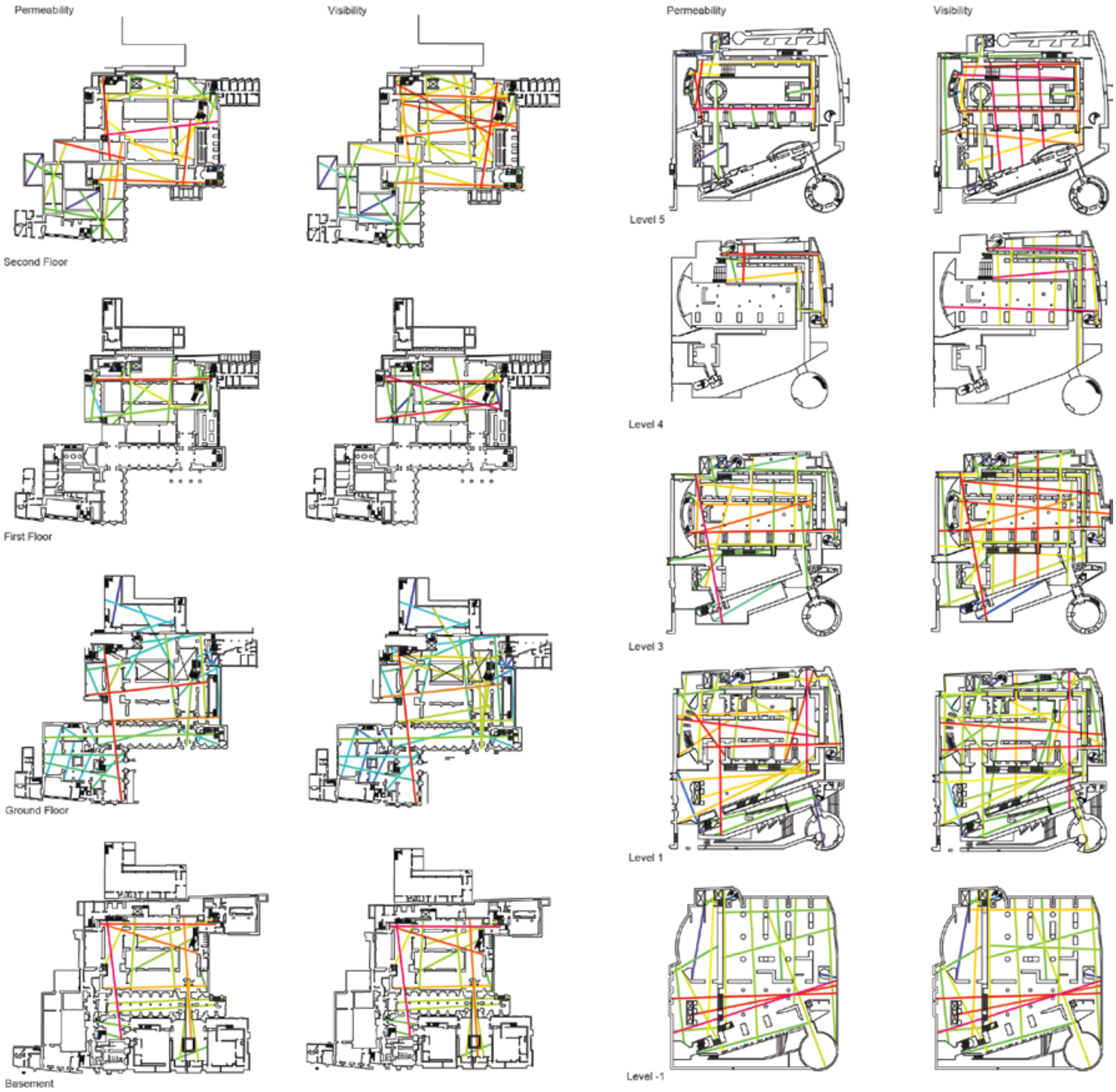


Figure 7. Axial analysis of permeability (left) and visibility (right) relations in the Ashmolean Museum (left) and the Museum of Scotland (right).

Permeability Analysis	Axial		Convex		VGA	
	Adjacent[3] Spaces	Mean Int. HH	Adjacent Spaces	Mean Int. HH	Adjacent Spaces	Mean Int. HH
Basement		1.71		0.74		6.4
Atrium A	2.05		0.93		7.08	
Atrium B	2.19		0.92		6.24	
Atrium C	2.09		0.87		6.83	
Ground Floor		1.37		0.68		4.74
Atrium A	1.80		0.82		4.94	
Atrium B	1.66		0.84		4.92	
Atrium C	1.78		0.71		4.66	
Atrium D	1.82		0.81		4.75	
First Floor		1.92		0.69		6.64
Atrium A	2.19		0.68		7.14	
Atrium C	2.27		0.58		6.53	
Atrium D	2.35		0.79		7.00	
Second Floor		1.18		0.68		4.54
Atrium A	1.29		0.70		4.68	
Atrium B	1.46		0.85		4.80	
Atrium C	1.29		0.61		4.23	

Table 6. Permeability integration values (HH) calculated for the Ashmolean Museum.

Visibility Analysis		Axial			Convex			VGA	
	Atrium	Adjacent Spaces	Mean Int. HH	Atrium	Adjacent Spaces	Mean Int. HH	Atrium	Adjacent Spaces	Mean Int. HH
Basement			1.75			1.88			6.40
Atrium A	2.68	2.14		3.43	2.29		7.22	7.02	
Atrium B	2.68	2.03		2.51	2.46		6.45	6.29	
Atrium C	3.00	2.17		1.33	2.44		6.87	6.87	
Ground Floor			1.85			2.13			6.29
Atrium A	2.80	2.14		3.55	2.66		7.92	7.37	
Atrium B	2.80	2.38		2.61	2.47		7.16	7.18	
Atrium C	2.80	2.64		2.35	2.55		8.35	8.35	
Atrium D	3.40	2.23		2.66	2.31		8.36	7.74	
First Floor			2.90			2.38			9.44
Atrium A	3.50	3.23		3.03	2.55		10.84	10.30	
Atrium C	4.17	3.20		2.24	1.87		8.80	9.78	
Atrium D	3.47	3.50		3.48	2.92		9.99	10.04	
Second Floor			1.54			1.53			5.11
Atrium A	2.44	1.89		2.51	1.74		6.51	5.94	
Atrium B	2.25	1.87		2.08	2.06		5.60	5.66	
Atrium C	2.25	1.72		2.45	1.22		4.92	5.13	

Table 7. Visibility integration values (HH) calculated for the Ashmolean Museum.

[3] Average value of the adjacent spaces surrounding the atria.

Intelligibility (R2)	Ashmolean Museum		Museum of Scotland	
	Basement		Level -1	
	Permeability	Visibility	Permeability	Visibility
Axial	0.89	0.87	0.87	0.83
Convex	0.52	0.84	0.38	0.78
VGA	0.45	0.65	0.69	0.73
	Ground floor		Level 1	
Axial	0.62	0.83	0.89	0.87
Convex	0.30	0.80	0.52	0.84
VGA	0.33	0.55	0.45	0.65
	First floor		Level 3	
Axial	0.81	0.84	0.91	0.92
Convex	0.55	0.85	0.23	0.83
VGA	0.74	0.83	0.35	0.31
	Second floor		Level 4	
Axial	0.55	0.72	0.78	0.89
Convex	0.33	0.73	0.52	0.85
VGA	0.40	0.59	0.42	0.87
			Level 5	
			0.84	0.88
			0.32	0.71
			0.38	0.65

Table 8. Intelligibility R2 values for both museums.

Permeability Analysis	Axial		Convex		VGA	
	Adjac. Spaces	Mean Int. HH	Adjac. Spaces	Mean Int. HH	Adjac. Spaces	Mean Int. HH
Level -1		2.03		0.99		5.52
Level 1		1.71		0.75		4.96
atrium A	1.93		0.83		8.52	
atrium K	1.81		0.85		7.53	
Level 3		1.96		0.84		5.61
atrium A	2.00		0.76		5.71	
atrium K	2.34		0.81		5.99	
atrium L	2.44		5.99		6.45	
Level 4		0.95		0.79		4.69
atrium L	1.00		0.89		4.98	
Level 5		1.15		0.78		4.68
atrium A	1.05		0.65		4.34	
atrium K	0.87		0.68		4.34	
atrium L	0.89		0.77		4.20	

Table 9. Permeability integration values (HH) are calculated for the Museum of Scotland.

Visibility Analysis		Axial			Convex			VGA	
	Atrium	Adjac. Spaces	Mean Int. HH	Atrium	Adjac. Spaces	Mean Int. HH	Atrium	Adjac. Spaces	Mean Int. HH
Level -1			2.16			1.97			5.75
Level 1			2.46			2.70			7.23
atrium A	3.03	2.84		4.90	2.94		8.73	8.50	
atrium K	2.79	2.68		3.21	3.33		7.00	7.70	
Level 3			2.31			2.59			6.62
atrium A	2.61	2.70		3.82	2.41		6.65	6.81	
atrium K	1.97	2.23		3.64	2.79		6.63	6.84	
atrium L	3.52	2.78		4.83	2.90		7.55	7.42	
Level 4			1.23			1.20			5.23
atrium L	3.03	2.12		4.63	2.55		11.65	11.4	
Level 5			1.66			1.84			7.92
atrium A	1.92	1.98		2.24	2.07		9.20	8.95	
atrium K	1.20	1.60		1.24	1.71		6.65	6.69	
atrium L	2.26	2.07		2.26	1.84		7.80	7.88	

Table 10. Visibility integration values (HH) are calculated for the Museum of Scotland.

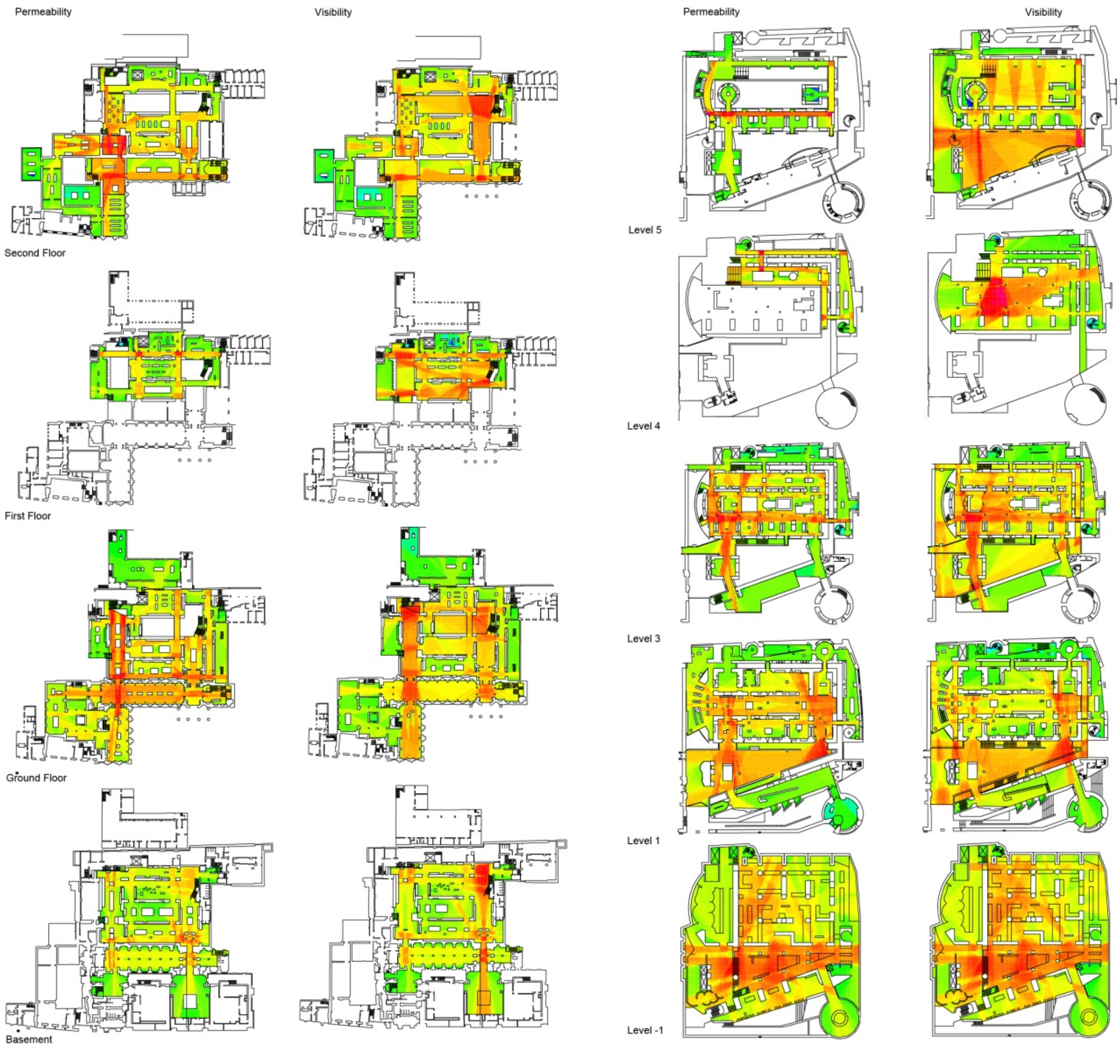


Figure 8. VGA analysis showing permeability (left) and visibility (right) relations in the Ashmolean Museum (left) and the Museum of Scotland (right).

5. Routes of exploration and the morphology of viewing

Having discussed the spatial properties of the two buildings, the discussion now moves to the observation study of visitors' paths. The relationship between space and users will be discussed floor-by floor, so as to explain the different ways in which atria relate to visitors' paths in successive horizontal levels.

The analysis of paths in the Ashmolean Museum reveals two kinds of exploration patterns. Exploration pattern 'a' refers to those visitors who on entering follow the main axis of the building (50%). Exploration pattern 'b' concerns the other 50% who turn left to the Cockerell axis. Of those visitors that follow pattern 'a', 68% traverse atrium A, 20% walk through atrium D, 12% pass through atrium B and none reaches atrium C (Figure 9). 60% of the visitors who reach atrium A, change floor level, within the first 10 minutes of their visit showing the effect of three-dimensionality on exploration. On the other hand, visitors following exploration pattern 'b' traverse the galleries first coming across all atria at least once while navigating (table 11). The two navigation patterns on the ground floor reveal a spatial exploration that has a twofold character: as a system in which three-dimensionality acts as a strong attractor of movement towards the atria, away from gallery spaces; as a sequential pattern where visitors encounter the atria through the gallery spaces at a later stage in the process. The differences between the two patterns of exploration, one related to the architectural effects of atria, the other to the impact of the gallery exhibitions, capture a competing relationship between the architectural and museological experience.

On the first floor, users were observed on arriving from atria A (exploration pattern '1a' – the continuation of pattern 'a' on the ground floor) and C (exploration pattern '1b' - the continuation of pattern 'b' on the ground floor) in equal numbers to highlight their differences. Visitors appropriate atrium C mostly for vertical movement and do not explore the galleries so extensively as people who arrive from atrium A. On Level +2, the exploration pattern '2a', initiating from atrium A, shows a penetration of paths deeper in the galleries with only 8% of the people reaching atrium C. On the other hand, the exploration pattern 'b', from atrium C, illustrates movement around atria A (64% use the stairs) and B showing that people are primarily attracted from the wide views and thereafter traverse to the galleries (table 11). In general, the amount of people looking up and down rises as levels ascend (from 16.4% on the ground floor to to 33.6% at the top level).

Overall, those that are attracted by atrium A on the ground floor (pattern 'a') continue to explore the galleries on the upper floors, while those that turn left on entering the ground floor move initially towards the atria on the upper levels and later on to the galleries. These patterns show that initially separated, the two patterns of circulation intersect on the higher floors, each compensating for the architectural or the museological experience that has dominated their exploration on the ground level.

Exp. Pat. a	Users	%	Exp. Pat. b	Users	%
atrium A	17	68%	atrium A	14	56%
atrium B	3	12%	atrium B	7	28%
atrium C	0	0	atrium C	1	4%
atrium D	5	20%	atrium D	4	16%
Exp. Pat. 1a			Exp. Pat. 1b		
atrium A	25	100%	atrium A	8	32%
atrium B	13	52%	atrium B	11	44%
atrium C	2	8%	atrium C	25	100%
atrium D	10	40%	atrium D	6	24%
Exp. Pat. 2a			Exp. Pat. 2b		
atrium A	25	100%	atrium A	16	64%
atrium B	9	36%	atrium B	4	16%
atrium C	5	8%	atrium C	25	100%
atrium D	12	48%	atrium D	5	20%

Table 11. Exploration patterns in the Ashmolean Museum.

The atria in the Ashmolean have a complementary relationship to each other. Atrium A functions as an orientation space with double the amount of people moving vertically through it (45%) compared to C (20%). Further, it acts as a destination area attracting movement and static activity. Atrium C does not attract horizontal movement but channels vertical circulation. Atria B and D are crossed by through-movement while also empowering the interrelationships among atria by offering open vistas. Further, the museum seems to shape exploration based on users' initial route and choices for vertical movement. The exploration patterns 'a' and 'b' present the museum to the viewers in a way which privileges a different perspective the former, the architectural perspective, while the latter the museological one.

The paths in the Museum of Scotland show a concentration on the left hand, side, which is adjacent to the Royal Museum of Scotland (RMS) on Levels 1, 3. On Level 1, atrium A is used from all the visitors (100%, table 12), with few of them (20%) moving to the peripheral galleries and no one changing level through the segregated stairs located in these spaces. The bridges crossing the shafts are used mostly as transitional spaces strengthening the aesthetic function of the shafts in the museum. The shafts do not seem therefore, to play a strong role in attracting movement and structuring orientation. In contrast, the platform on Level 3 (between atrium L and the front gallery) is widely used (84%), suggesting that atrium A is a stronger attractor of movement than the shafts in the building. Moreover, 60% of the times visitors engage with the third dimension happen around atrium A.

Atrium L is the second most traversed void, in terms of through- and to-movement, as well as the second atrium in terms of the number of people that engage with the third dimension. As people ascend, they are more attracted to the views looking at the atria (Level -1: 5.16%) compared to the upper floors (~23% each), showing that the effect of the third dimension becomes stronger at higher levels. On Levels 4 and 5, the linear and sequential system of the galleries predetermines movement making all paths uniform (Figure 9). People meet in procession and their traces repeat the layout of each floor, which surrounds atrium L (88%). The bridges encourage people to make small detours. On Level 5, the balcony situated off the main circulation overlooking atrium A, attracts people who use it as a destination viewing point.

	Users	%
Level 1		
atrium A	50	100.0%
atrium K	15	30.0%
Level 3		
atrium A	42	84.0%
atrium K	33	66.0%
atrium L	36	72.0%
Level 4		
atrium L	43	86.0%
Level 5		
atrium A	30	60.0%
atrium K	15	30.0%
atrium L	44	88.0%

Table 12. Exploration patterns in the Museum of Scotland.

Visitors who enter the museum from the RMS through Levels L1, L3 move less towards the galleries compared to people who enter from the main entrance continuing their journey in these floors from other levels within the building. This may be associated with their physical tiredness or the fact that they are overwhelmed due to the spatial complexity of the Museum. Visitors from RMS mostly concentrate around atria A and L, with 40% of them changing floor through atrium A, and 52% returning back to the RMS after a while. These findings illustrate the effect of atrium A regarding their decisions to change levels in the museum.

It was previously said, that in this museum the hierarchical relationship between atria A and L is established from the beginning of one's journey. The path traces and spatial analysis show that

Atrium A attracts the majority of visitors introducing the internal structure, providing orientation and acting as a reference point during their exploration, mostly on Levels 1,3. Atrium L functions as a destination and as a through-movement area, housing some of the collections, while acting as the entrance to the peripheral galleries from Level 3 and upwards. The shafts do not play an orientation role due to the limited visual information they offer but are mainly for creating architectural effect. The bridges provide additional route choices being appropriated mostly on Levels 4 and 5. This is because the layout predetermines circulation, which passes through them. Visitors coming from the RMS are mostly attracted to atrium A, which adds to their decision for level change, instead of moving horizontally towards the galleries.

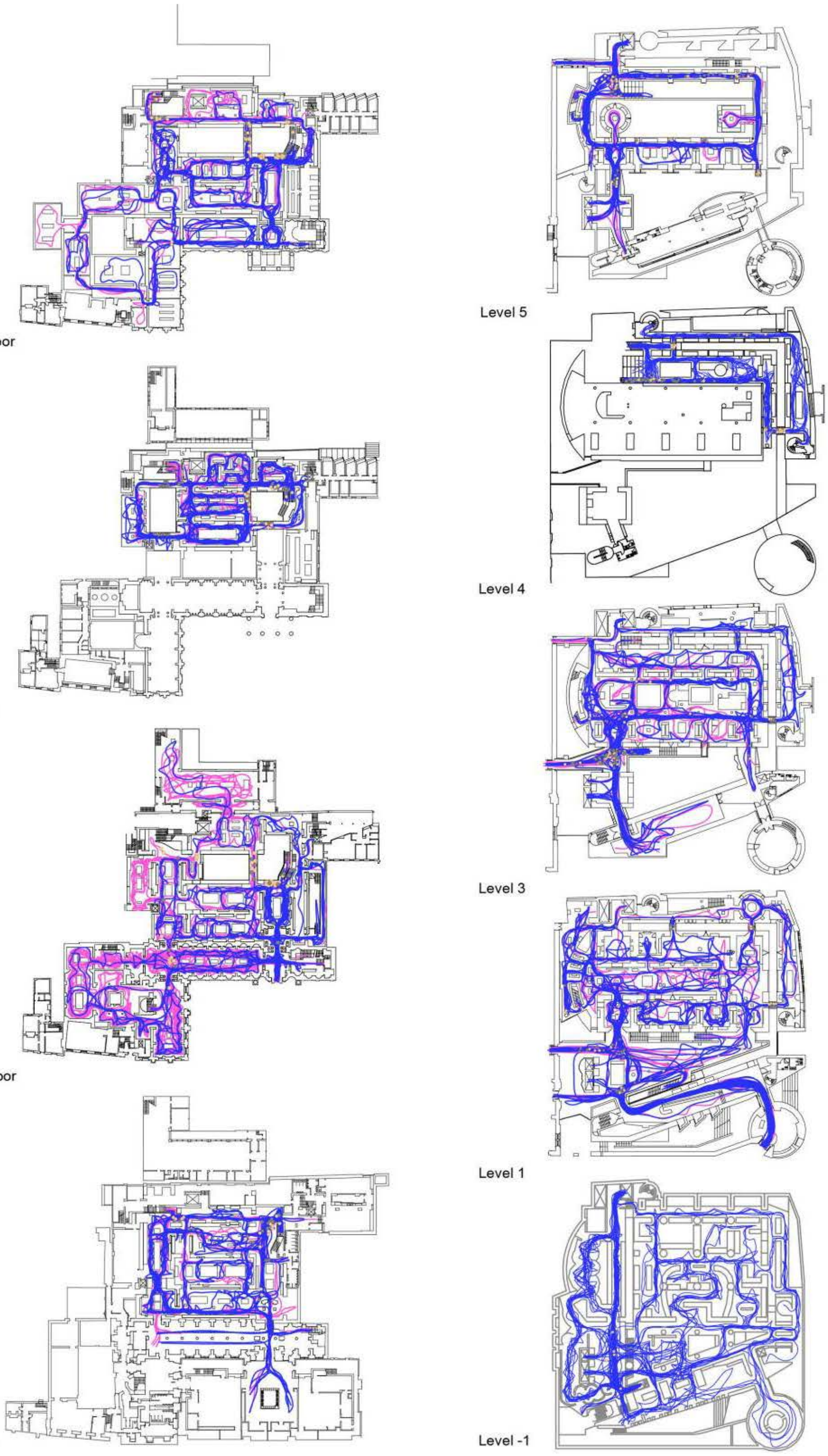
On the whole the two buildings have striking similarities in terms of overall size and use of a number of atria in structuring space and circulation. However, their architects seem to approach atrium design in different ways. Mather uses a set of similarly shaped and modestly sized atria to integrate spaces, with one atrium achieving greater strength from the rest but all equally participating in structuring compositional relationships and movement in building. Benson and Forsyth on the other hand, use atria as compositional devices of great symbolic strength, vary their shape and size to differentiate one from the other, and establish hierarchical relationships between them affecting the ways in which people cross each atrium. In particular, atrium A plays a stronger role regarding users' navigation on Levels 1,3, while on Levels 4 and 5, atrium L attracts more visits due to the spatial configuration which surrounds the latter.

Space syntax analysis includes agent-based modelling which simulates movement flows and is used to predict and visualize how the two-dimensional configuration could shape movement. Agent analysis in this study is used comparatively with real movement so as to explore whether there are differences between the spatial properties that affect human movement in two and three dimensions.

In the Ashmolean Museum, the agent analysis illustrates relatively low values around the atria (Figure 10). This finding contradicts the syntactic visibility analysis and the on-site observations (Figure 9) showing high levels of integration around the atria and movement traces. The lack of confluence of agents' paths around the atria is affected by the fact that for agent analysis these spaces feature as physical and visual barriers. In general, agent models lack the ability to take into account vertical connections and horizontal ones through vistas facilitated by atria and voids. Effectively, not only the voids but also the axes leading to them are not picked up compared to real movement, specifically along main axis on the ground floor and the western on the basement (Figures 9, 10). So, the effect of the third dimension on visitors' perception and spatial decisions is clearly highlighted here in the difference between agents' and peoples' paths. The former is associated with the amount of people reaching and stopping around the atria and their patterns of circulation previously discussed. The latter are based only on permeability relations on two dimensions.

Similarly, in the Museum of Scotland the agents show inconsistencies when compared to real time observations. On the ground floor, the curvilinear atrium on the western part of the building, is widely used by the visitors contradicting the agent analysis (Figures 9, 10). Moreover, the peripheral galleries do not concentrate simulated movement, whereas people appropriate them widely (42%). Additionally, on Level 5 the balcony overlooking atrium A and the platform overlooking Level 4 do not perform well in terms of agent movement (Figure 10). In terms of real paths, they act as destination points by offering expansive three-dimensional vistas and global orientation. Finally, on the basement, where no atria exist, the agents and visitors present similar patterns, indicating that when permeability and visibility relations are the same, simulated movement illustrates a closer image to real world patterns.

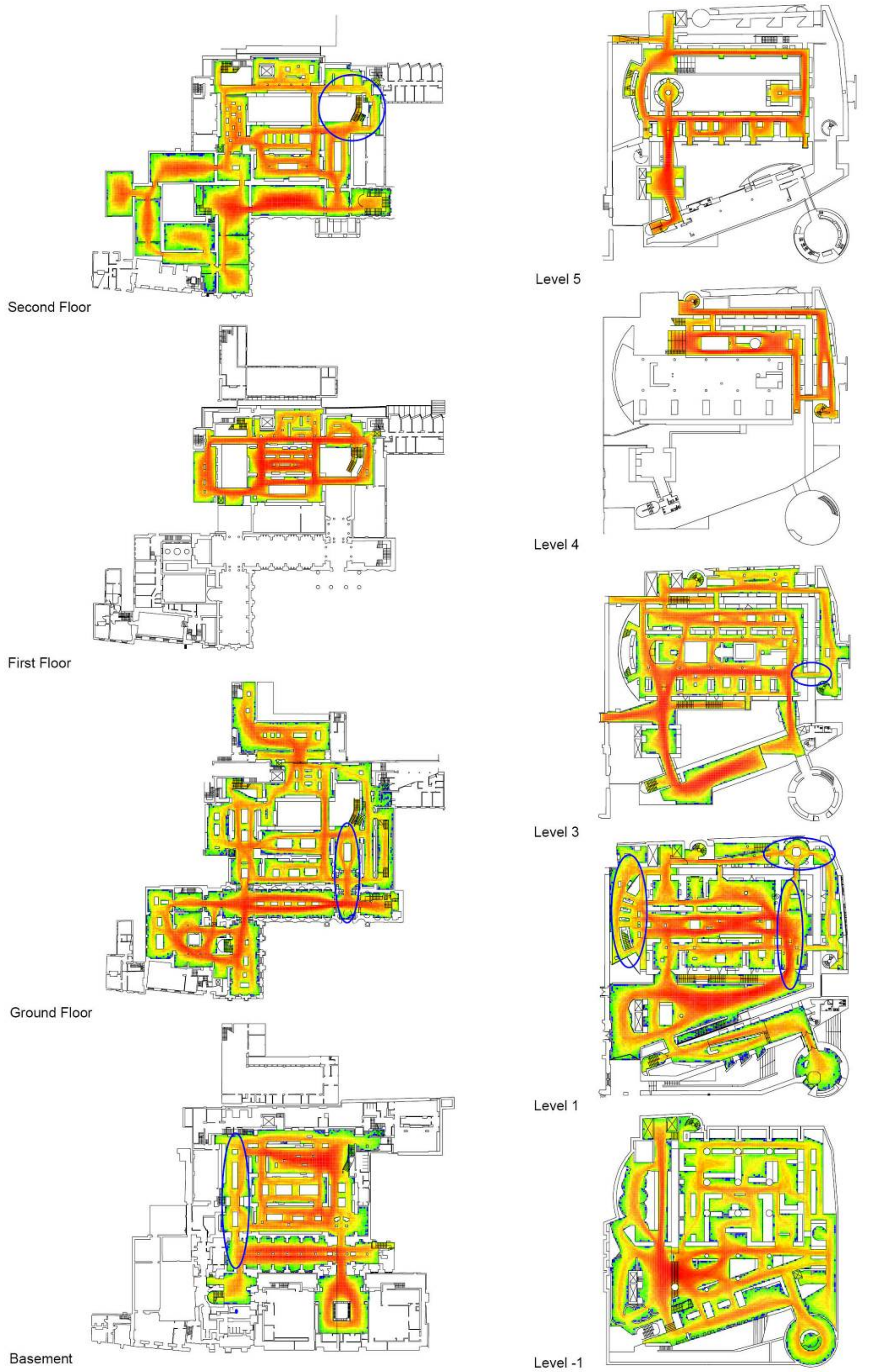
Effectively, the analysis shows that the three-dimensional voids can act as negative attractors in terms of simulated movement, repelling motion around them. In contrast, humans are positively attracted by the existence of the atria offering spatial and visual information on the three-dimensional architectural design. The observed differences between the two-dimensional simulated and the three-dimensional real movement strengthens the hypothesis that certain spatial decisions are affected by the third dimension.



Blue traces in the Ashmolean show exploration pattern 'a'. Pink traces show exploration pattern 'b'. Blue traces in Museum of Scotland enter from its entrance. Pink traces come from Royal Museum of Scotland. Yellow stops: paused movement to look up/down; grey stops: engage with the third dimension while walking.

Figure 9. Traces in the Ashmolean Museum (left) and the Museum of Scotland (right).

6. Agent based models



Red areas show high movement rates and blue ones low. The circles signify the areas where differences are observed with real movement. 50 agents are released with standard properties (Turner and Penn, 2002): a walking pace of about 1.5ms-1, three steps to decision and a field of view of 170 °.

Figure 10. Agent-based models for the Ashmolean Museum (left) and the Museum of Scotland (right).

7. Conclusions

This paper illustrates that the museums' three-dimensional architectural design impacts significantly in users' navigational processes. The atria in the two buildings are compositional devices that link the old with the new fabric, bring light inside very compact buildings, structure vertical circulation and the relationship between galleries. Exploring their impact on the spatial structure of the museum, we saw that they attract integration to themselves (particularly in terms of visibility VGA) and help to structure the relationships between exhibition spaces and the three dimensional organisation of the buildings. However, significant differences exist in terms of how this relationship is structured, and the ways in which it impacts on movement patterns.

The voids in the Ashmolean act as key reference points of the circulation and conceptual structure, creating a sense of visual unity intensified at the core of the building. The core is deeply located inside the museum attracting movement to itself, interconnecting the central and segregated galleries and facilitating global orientation. All atria have a complementary relationship to each other, strongly supported through wide and overlapping vistas while revealing the internal structure to the users. Atrium A acts as an orientation and destination place while atrium C facilitates mostly vertical movement. Atria B and D acquire a through-movement character supporting the strong visual core. Especially atrium A works as a pivoting point around which two three-dimensional exploratory patterns meet (patterns 'a' and 'b'), interfacing the museological with the architectural experience. Overall, visitors concentrate around the atria independently of their initial route choices, capturing the impact of the three-dimensional architectural design on their navigation and spatial experience.

The Museum of Scotland proves to be a more controlled, protected and sculpted environment acting as a mechanism that enhances a rich three-dimensional spatial experience created by the interlocking of voids and shafts within its configuration. The atria act as strong media for architectural expression shaping the compositional structure of the museum. Although the architects invest greater volume in the voids than is invested in the Ashmolean, these spaces are not well interconnected with each other potentially affecting the ways in which visitors can piece together a three-dimensional picture of the building in their mind. Particularly, atria A and L have a hierarchical relationship to each other sequencing the visit through one atrium controlling access to the other. Although axially interconnected, they provide orientation, they are physically separated through thick walls screening views and creating surprise. Atrium A acts as an 'introduction' and orientation area, facilitating horizontal and vertical movement. Atrium L controls horizontal navigation towards the inner and peripheral galleries acting as a secondary orientation and through-movement area. People do not appropriate the shafts for orientation, nevertheless they cross through the bridges in order to penetrate deeper to the peripheral galleries. Visitors who arrive from the Royal Museum of Scotland are mostly attracted to atrium A, which demonstrates its strong role within the three-dimensional system.

Findings from the agent analysis in both museums do not correspond with real data, strengthening the hypothesis that the third dimension affects navigation. Further virtual reality work should expand on this, in order to examine to what extent spatial alterations in the existing three-dimensional layouts could correspond to the information presented through space syntax measures.

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