Proceedings of the Ninth International Space Syntax Symposium
Edited by Y O Kim, H T Park and K W Seo, Seoul: Sejong University, 2013

VISIBILITY AND PERMEABILITY RELATIONS IN THREE-DIMENSIONAL CULTURAL ENVIRONMENTS:

The Ashmolean Museum as a case study

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Abstract

Museums, as substantial cultural environments, structure and affect human perception, navigation and movement depending on the spatial configuration of each setting. This paper focuses upon permeability and visibility measures used in space syntax analysis and the impact of the third dimension on visitors' performance. The research questions it explores are: a. is there a second system of spatial relations created by visibility other than one formed by permeability patterns? b. what role do the atria play in the ways in which visitors navigate and experience the museum; which is the role of the third dimension in these spaces?

The purpose of the paper is to investigate the research questions in real environments (atria museums) and those based on agent simulations. It looks at the Ashmolean Museum of Art and Archaeology in Oxford, opened in 1683 and renovated in 2009 by Rick Mather Architects. The museum contains atria spaces, which are intended to aid the exploration of the three-dimensional visual relations through the extensive use of transparent, semi-transparent and opaque surfaces in its design. Three main circulation spaces (atria) exist in the museum, which facilitate vertical movement through staircases located in them while also visually interconnecting the different floor exhibitions. Additionally, these spaces offer the potential of route choice to users within the building.

The research looks at how the three atria influence peoples' behaviour firstly, through the route choices they offer for movement (vertical and horizontal); secondly, through the ways in which they enter people's visual fields with accessibility and visibility relations; thirdly, through on site observations of human activity inside these spaces; and finally, through agent modeling. All methodologies are integrated in order to explore the degree of their correlation and impact on peoples' cognition and navigation.

The findings resulting from the research illustrate that the permeability and visibility patterns analyzed separately, in terms of methodology, bring out different results explaining how the museum's layout affects and structures navigation and perception in two complementary ways. The architects' design intention to connect the old with the new building is realized with the use of the atria. Moreover, the voids providing rich-cross visibility around and through them enhance the role of the third dimension in peoples' navigation, orientation and exploration patterns. Their design properties and verticality within the museum's three dimensional configuration split visibility from permeability relations, thus establishing their contribution to peoples' overall knowledge of the surrounding spaces. The museum therefore creates a sense of unity and continuity in its arrangement of the various galleries and spatial layout. To conclude, the wider purpose of this paper is to contribute to the deeper understanding on the ways architects design museum environments and therefore influence visitors' spatial experience.

Keywords: *Museums, spatial cognition, navigation, Space Syntax, three-dimensionality, visibility*

Theme: *Building Morphology and Performativity*

'Entered through the Cockerell façade into a day-lit atrium, which is modest in plan yet dramatic in section, rising through six floors with a subtly curved staircase cascading down one wall, the atrium unifies the museum. The route navigates its way through 39 galleries with a clever interleaving of double and single height spaces creating a rich spatial journey', wrote by Mark Lawson, Judge, at the RIBA awards 2010 on the Ashmolean Museum (source: http://www.rickmather.com).

1. Introduction

This paper presents a study on the Ashmolean Museum in Oxford, concerning visibility and permeability measures used in space syntax analysis and the impact the third dimension has on visitors' navigation within the spatial layout. The research questions it explores are: a. is there a second system of spatial relations created by visibility other than one formed by permeability patterns? b. what role do the atria play in the ways in which visitors navigate and experience the museum; which is the role of the third dimension in these spaces? The specific museum was chosen as a case study since it contains three atria spaces which enhance the role of the third dimension and are differently configured within the building, formulating spatial cognition and navigation in various ways. The research questions therefore, refer to the wider issue of how the spatial layout of atria museums structures exploration, navigation and spatial cognition, effectively showing the unique spatial experience each cultural environment offers.

We address these research questions by examining initially the spatial layout of the building. Our examination focuses upon the ground floor of the museum as a pilot study. This is done in order to determine the movement choices people make upon entering the museum and the decisions they take being crucial for their navigation in the rest of the floors.

The questions underlying the study are explored by firstly analysing the role the atria play on the configurational properties of the layout and secondly on the visitors' cognitive and movement patterns. Special importance is given upon the comparison between permeability and visibility properties, as this relation captures the role of the third dimension in peoples' navigation. The design properties of the voids and their verticality within the museum's three-dimensional configuration split visibility from permeability relations. The relationship between visibility and permeability therefore, allows a study of how visibility across voids and route structure are combined influencing navigation and exploration. In this manner therefore, the role of the third dimension is captured in a two-dimensional way, which is expressed as the scope of the present research.

We look at how the atria influence peoples' patterns of navigation firstly, through the route choices these spaces offer for movement (vertical and horizontal). Secondly we examine the ways in which atria enter peoples' visual fields in two dimensions with accessibility and visibility relations gained from axial, convex maps and from visibility graph analysis. Thirdly, we examine on site observations of human activity inside these spaces. Finally, we use agent modeling in order to compare their spatial behaviour with real movement data retrieved from the on site observations to capture differences that could illustrate the role of atria in their decision making process. All methodologies are integrated in order to explore the degree of their correlation and impact on peoples' cognition and navigation.

The findings of the investigation show that in the Ashmolean museum, there are two systems of spatial relations created by the permeability and visibility patterns. Both affect peoples' perception therefore structuring different circulation and exploration patterns depending on which system people appropriate. The atria act as places for orientation and circular movement offering information about the third dimension coupled with the two-dimensional spatial configuration about route choice. Their strategic locations constitute them as gravity points which draw people to the deeper part of the museum; opening up its spatial structure for them to explore visually and decide on their horizontal or vertical movement. Additionally, the study shows that the atria strengthen the visual coherence of the museum and make the building work as a lively mechanism enhancing movement. Finally, the rich cross-visibility from and around the atria amplifies the probabilities for visual encounters among visitors who stand or move around them enhancing the dynamic character of the museum.

2. Morphology of space

We start by providing a background to the Museum that places it in a context and move next to describing its properties of spatial configuration (figure 1a). Initially established in Oxford in 1683, the Ashmolean Museum was renovated by Rick Mather Architects in 2009. The building is located at Beaumont Street, at the rear of the Greek revival building designed and built by Charles Robert Cockerell as the University Galleries (1845). The front part of the museum consists of double height galleries while the back part consists of galleries which are mostly single storey in height. The new building has 6 storeys including the lower ground floor. Additionally, the architects' design intuition was to open up the museum right back to pull the visitors through. The bridges interconnect double height areas and offer panoramic views to the galleries.

As the architects of Rick Mather claimed in their interview (BBC Oxford Ashmolean series) their design concept for the atria had as a goal 'that the visitors would look down and around to see different pieces of work that they did not know about their existence in the museum and they would want to visit them without using a map'. In other words, their ultimate design goal was to open the heart of the museum for the people and make it as legible as possible through the extensive use of vistas within its layout. The three dimensional visibility from one floor to another played an important role in order to achieve their concept and strengthen their design solution (figure 1, 3D model).

The floor plan is designed according to some axes running from the front to the back structure of the museum and from east to west. The two major routes, set up by Cockerell, intersect at the entrance of the building (figure 1a). The axes, stretching from east to west, are designed so as to connect the various galleries and public spaces of the museum together. Both types of axes contribute to the clarity of the plan, organizing space in a legible manner that is likely to facilitate global orientation. The main axis connects the entrance to the atrium A while the Cockerell axis starts from the entrance and is perpendicular to the main axis. Also it passes through the galleries 21, 26, 27, 25 and leads visitors to the western part of the building. The western axis connects the galleries numbered 22, 18, 16 with the atrium C at its far end.

The classification of the galleries on the ground floor is realized in the following manner. The gallery numbered 9 is the orientation gallery which introduces key themes and story-trails to follow throughout this floor, located at the main axis. The galleries 10, 11 on the eastern part of the museum accommodate Chinese exhibits and the ones at the back part, numbered 12-16, include Roman and Greek themes. On the western part of the museum the gallery 17 shows items from European Prehistory. The ones from 18-21 include Greek and Cyprus exhibits occupying mostly the central space of the ground floor. Finally the galleries 22-27 consist of the Egyptian exhibits and are located as part of the western axis and adjacent to it.

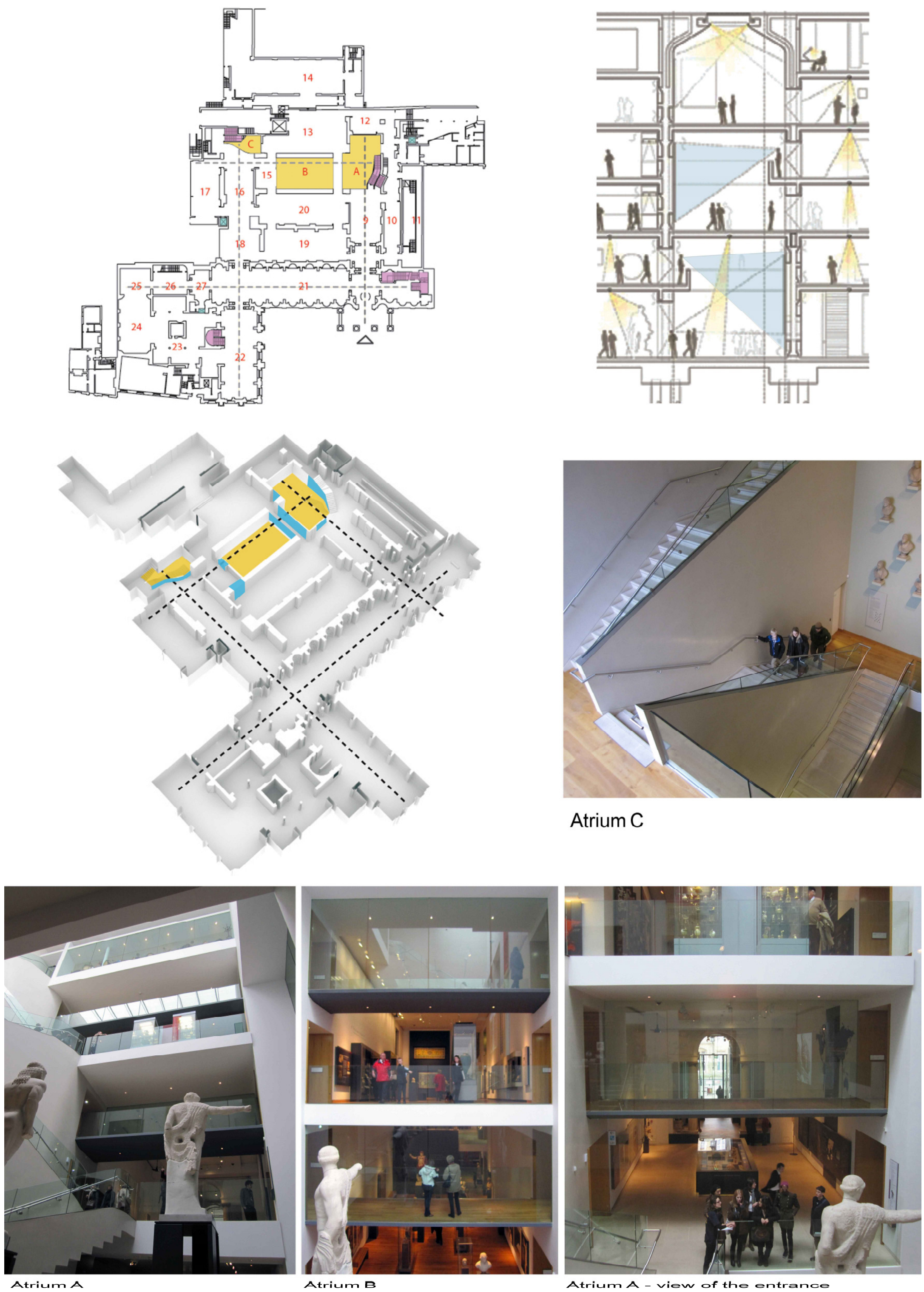


Figure 1: Plan and section of the ground floor. The circulation axes are signified in grey colour on the plan, with the main axes intersecting at the entrance of the building, (b) 3D model of the ground floor highlighting the location of the atria, the axes and the glazed facades, (c) different views of the atria A, B and C illustrating the amount of vistas interconnecting the floors and galleries.

The atria spaces are located at the back part of the museum's extension, as illustrated in figure 1 and named accordingly as A, B and C areas. Atrium A is located at the northern end of the main axis and offers vertical connection to the various floors. Atrium B is designed as a double height space situated at the centre of the back part of the museum. It is surrounded by bridges which connect galleries on the same floor. Finally, atrium C is designed at the northern end of the western axis offering as atrium A vertical connection through its staircases to the rest of the floors.

Natural light permeates the interior through large windows on the roof. As natural light enters the building from above it spreads out to the single and double height galleries, which are interconnected to the vertical atria (figure 1b). At the same time, a large window at the sidewall of the western atrium offers a visual connection to the sky and the surrounding space of the building. Both void spaces connect the lower ground to the 6th floor and organize vertical circulation accommodating the staircases.

The architectural modern design of the extension and especially the atria spaces therefore are mostly characterized by the use of transparent glazed surfaces offering wide views to the surrounding galleries (figure 1, 3D model). Their location, with the atrium A aligned with the entrance, atrium B at the centre of the museum's width and the atrium C at the end of the western axis, constitutes them as significant places for orientation for the visitors. Moreover, figure 1b illustrates the amount of visibility one has while standing around the atria or even from a distance. Their spatial layout with their design properties leaves unobstructed views throughout the horizontal and the vertical direction. When people reach the atria, or ascend and descent through their staircases, they have the chance to acquire a panoramic overview of the galleries and various levels of the museum first before deciding on which route to follow. Additionally, the design of the stairs with their stepping back as the floor changes leaves more empty physical space and advances the visibility area for the building.

The analysis of the museum using J-graphs shows that the relationship between the atria and the galleries is based on continuous visibility and permeability rings. Two different J-graphs have been constructed, with the first one showing permeability and the second visibility relations. The permeability J-graph (figure 2a) is drawn from the entrance of the museum and is 10 convex steps deep. The permeable interconnections between the galleries are illustrated as rings of continuous accessibility networks. Looking more closely at the J-graph and the configuration of spaces classifying them in 'a','b','c' and 'd'[1] spaces we realize that 47% of the ground floor spaces are 'd' type spaces, that is, spaces lying on at least two rings of circulation creating more route choices (Hillier 1996). 35% of spaces are 'c' type spaces lying on a single ring. The remaining spaces are a' and b' type of spaces (10% and 8% accordingly). We can therefore suggest that the way in which the galleries and the atria are configured through ring-like circulation patterns result in a museum environment which is configured as a place for continuous movement and circular navigation. These patterns encourage browsing and exploration which is informal and relaxed. This means that visitors are not forced to follow a specific route through the museum.

[1] Hillier (1996: 321) describes four topological types of spaces: a-types (links=1 deadends); 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).

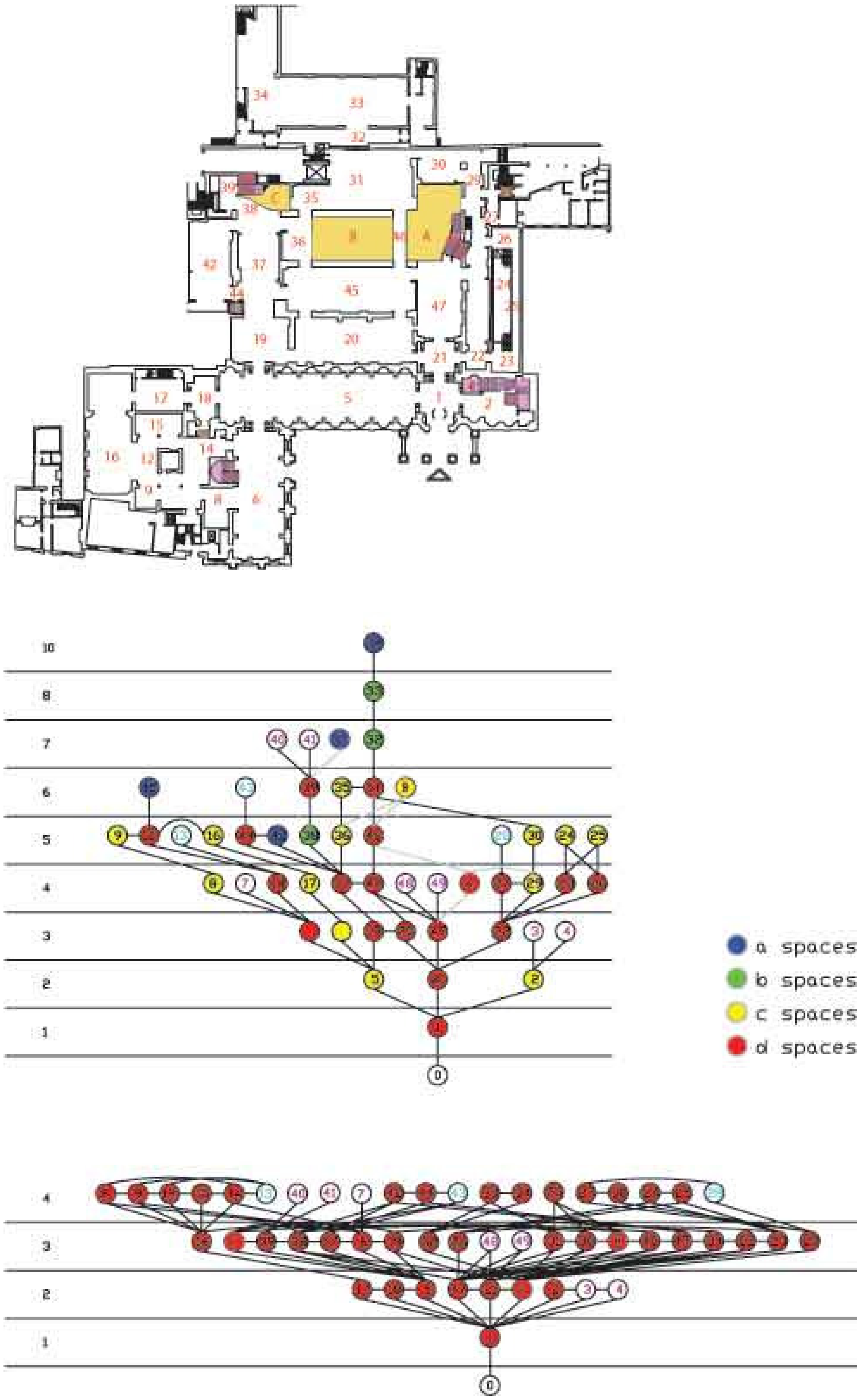


Figure 2: Justified graphs drawn from the entrance of the Ashmolean museum; (a) J-graph showing permeability relations, (b) J-graph showing visibility relations.

Smaller sub-rings are created due to the illustration of the atria in the permeability J-graph, as spaces drawn in relation to the rest of the galleries (figure 2a, colored in grey). The effect of the voids is mostly apparent at the northern part of the museum where they are located. The atrium A is characterized as a d-type space, located 4 convex steps deep from the entrance and is directly visible on entering the building. The atrium B is a c-type and the atrium C as an a-type space. Both atria B and C are 6 convex steps away from the entrance, and not directly visible from it. The fact that the atrium A is a d-type and nearer and visible from the entrance than the atria B and C, constitutes it as a transitional place and area for peoples' orientation due to its configuration in the network of the museum. The atrium C, as a dead-end in terms of its configuration on the ground floor, weakens its role as a place for orientation in the building.

Continuing with the analysis of the visibility J-graph (figure 2b), it seems that the graph is 4 convex steps deep. The visible relations between the galleries and the atria are illustrated through the amount of d-type spaces that are created. All of the areas of the museum on the ground floor belong to one or more visual rings. The atria are also characterized as d-type spaces, with the atrium A being 2 steps deep from the entrance and the atria B and C 3 steps away.

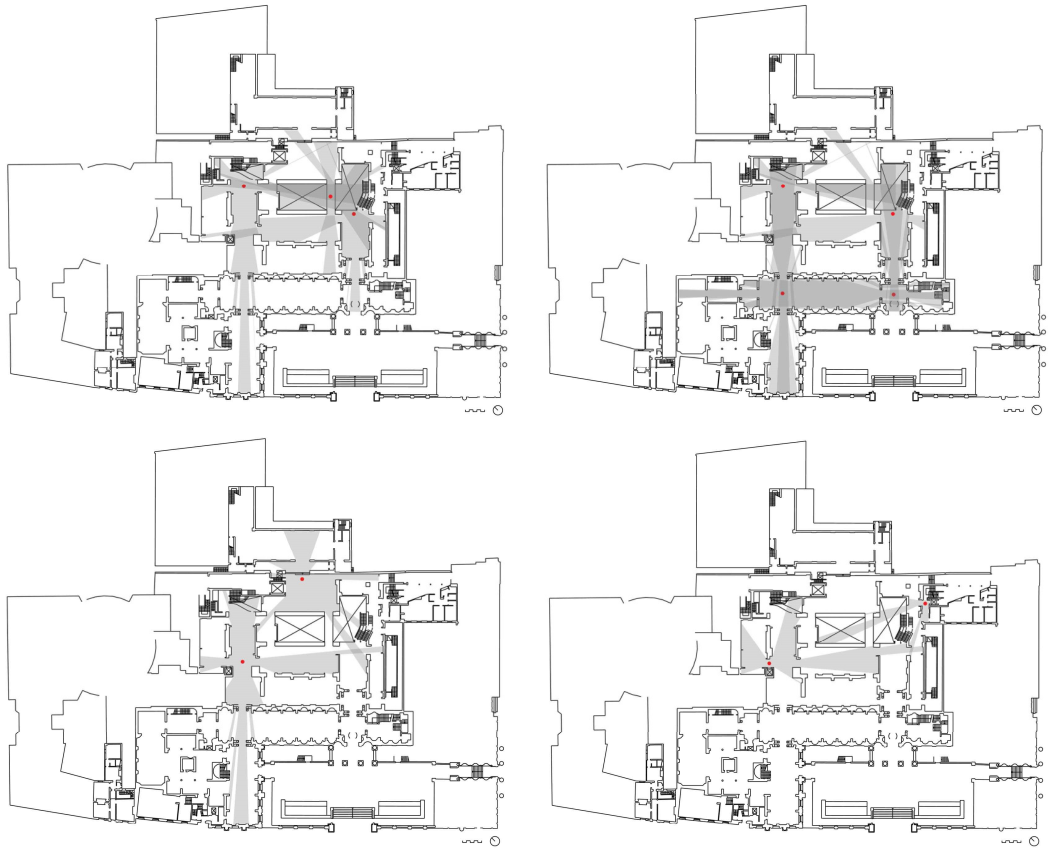
If we compare the permeability with the visibility J-graphs, we realize that the latter is much shorter in terms of depth, meaning that people can grasp more easily the structure of the museum upon entering due to the amount of visual relations that are offered. The extended use of glazed surfaces around the voids creates strong visual and permeable interconnections between the galleries. Moreover, the fact that in the visibility J-graph all of the spaces, including the atria, are d-type ones signifies that they offer route choice, therefore more chances that people will come across them. The role of the atria in the museum enhance the circulation in both vertical, due to the location of the staircases in the atria A and C, but also in the horizontal dimension. This accordingly leads to the result that the 3d articulation offering information about the third dimension is coupled with the spatial configuration offering information about route choice.

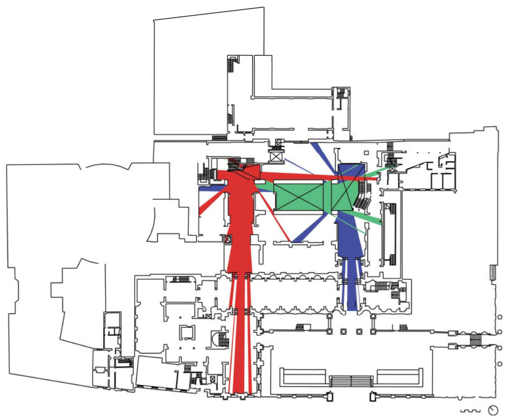
3. Isovists

From a first view point it seems that the museum creates a sense of unity and continuity in its arrangement of the various galleries. These are organized based on the themes of 'Crossing Cultures, Crossing Time' arranged in a chronological order according to floor by floor. As the Director Dr Christopher Brown stated, 'the interlinking of gallery spaces and the carefully constructed views and vistas on and between floors' are designed in a way that 'the relationships between galleries are often as important as the galleries themselves' (Ashmolean, 2009: 1). Tzortzi argues that the emphasis in the Ashmolean museum is 'more on visual rather than movement relations' (2011, p. 31). The strong visual axes penetrate throughout the museum's galleries interlinking them between the various floors, with the aid of the atria (figure 1, section). These perspective vistas terminate in some cases on blank walls. For instance, in the atrium A a wall interrupts the visual field available immediately on entering the museum. This wall acts as a visible barrier for the galleries behind the atrium (figure 3a).

Various isovists were constructed from different points around and near the atria (figure 4, top left image) to illustrate their extent over the voids to the various galleries surrounding them. Also it is clear that all three atria are intervisible from each other. The next image (figure 3a, top right) shows the extensive amount of vistas from the intersections of the axes (figure 1), constituting them as important junctions in the museum for peoples' orientation and navigation.

The sequence of these continuous changing vistas, as one navigates around the museum, creates an explorative atmosphere with the spaces flowing into each other, emphasizing the dynamic sense of space. The museum unfolds while travelling along a sequence of spaces, enhancing a strong visual and spatial experience. On the other hand though, as Tzortzi (2007, p 10) argues, in relation to the Ashmolean, that 'providing the viewer with a large flow of visual information beyond the space he is in, means reducing unexpectedness and spatial anticipation, and decreasing the impact of visual impressions'. This fact is associated with the quality of the spatial experience one acquires while navigating through the museum.





	atrium A	atrium B	atrium C
Area (m2)	97.94	86.23	38.00
J-graph	d-type	d-type	d-type
Longest axial line length (m)	38.61	39.95	61.92
Isovist Area	363.86	202.35	368.61
Isovist Perimeter	324.44	198.28	427.66
No of visible convex spaces	11	8	14

Figure 3: (a) Isovists drawn from various points (colored in grey) on the ground floor of the museum. Bottom-left image shows the isovists from the centre points of the three atria, (b) table illustrating the spatial properties of the atria and the isovists drawn from the centre of each atrium.

The analysis of the isovists shows that upon entering the museum the visual field splits in two directions, either towards the main axis, driving people into the core of the museum where the atria are located, or to the Cockerell axis, towards its western galleries. The main axis offers wider vistas around the galleries and throughout the atria compared to the Cockerell axis which drives them directly to the Egyptian part. Moreover, the galleries which are located along the western axis, not directly connected to the atria A and B, show narrower isovists in relation to the galleries which are adjacent to them (figure 3a, middle left). Furthermore, the locations of the lifts connecting vertically the floors are quite cut off from the visual fields connecting them to the entrance and the atria. This causes disorientation or local sense of space because vistas do not penetrate throughout the whole length of the museum. In these cases it would be interesting to examine how the wide and expansive isovists overlooking the atria and revealing the volume of space affect peoples' spatial experience.

Finally, isovists were drawn from the centre points of each atrium (figure 3a, bottom left) to examine the atria comparatively. It seems that their visual fields are not restricted to the local scale of their adjacent spaces; they enter up to 14 continuous convex spaces. Also the atrium C which has the most visual connections, offers them in a linear manner compared to the atria A and B which are surrounded by galleries and have 360 degrees views to them. Therefore, the type of isovist every atrium creates results in different ways of appropriating it as the observation studies will show later on. To conclude, with the atria being d-type spaces (figure 2b) and their isovists covering distant galleries, constitutes them as places for orientation and continuous movement to, around and through them providing vertical connections to the rest of the floors.

4. Analysing the Ashmolean museum with syntactic concepts

The study will now move to the analysis of the building's layout by applying syntactic methods on the plan, widely used in Space Syntax research. Axial analysis was applied on the ground floor of the Ashmolean with two different objectives. The first objective was to obtain accessibility measures illustrating spatial relations between the galleries and the potential for movement within them. The integration measure, shown in figure 4a, highlights the western axis (integration HH=2.50) penetrating the galleries 16, 18, 22 and the axis passing through the gallery 20 reaching the main atrium, as the most integrated ones with the mean integration value being 1.37. Moreover, we realise that the intention of the architects to strongly connect the old with the new part of the museum succeeded, since the integration core of the axial system is intensified around the galleries 18, 20 and 19 and located in the centre of the building. Concerning the integration values of the axial lines surrounding and connecting the atria to the rest of the spaces, they appear comparatively lower, as they are situated just off the integration core, in terms of permeability. Finally, the galleries 22-26, 12-14 and 11 which are not directly accessible from the core of the museum seem to be segregated and do not offer much potential for peoples' movement.

The second objective was to compare the accessibility axial analysis to the visibility axial structure (figure 5b). In this case, the visibility axes describe the extent of visual fields that pass through wide and narrow openings with glazed facades, windows and doors connecting spaces which are not directly accessible one from the other. This effectively changes the integration values of the visibility axial map in relation to the permeability one. Specifically, the mean integration value rises from 1.37 in the accessibility axial analysis to 1.85 in the visibility one. We notice that the most integrated visibility axis remains the western one with an integration value of 3.40. Interestingly enough though, if we compare the integration core in the two maps, the atria seem to become part of it in the visibility analysis, meaning that they create the potential for people to move deeper into the museum while spreading out movement around them. Furthermore, the main axis in the visibility map, connecting the atrium A with the entrance, is more integrated (integration HH=2.47) compared to the permeability one (integration HH=1.69). Even the more segregated galleries (22-26, 12-14 and 11) acquire more integrated connectors to the core of the building, providing them with more potential for movement.

The comparison between these two axial analyses highlights the different effect the atria have on the museum's permeability and visibility patterns. In the first case, we regard them as spaces which are physically non accessible places. We then realize that the integration core is limited up to their location and does not go deeper than that, constituting the northern galleries as quite segregated places for visitors to reach. Also the atria are quite cut off from the main integrators, meaning that people would not be directly attracted to them. In the second case though, the atria influence the integration values as connecting visual elements therefore the integration core expands and makes the layout much more open and visually accessible for people. The central and northern galleries of the museum become unified and present more potential for movement due to the expanded visual core including the atria.

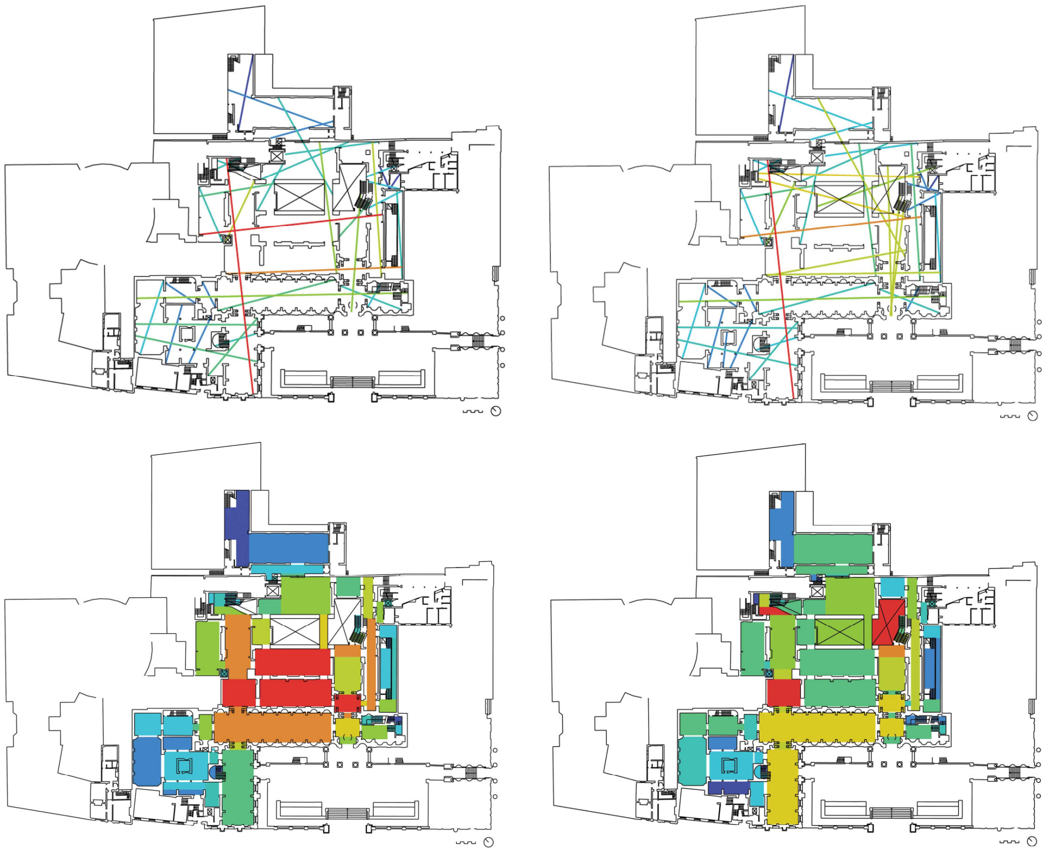


Figure 4: Integration (radius n) is illustrated in the (a) axial map of the ground floor showing accessibility, (b) axial map of the ground floor showing visibility, (c) convex analysis showing accessibility, (d) convex analysis showing visibility.

Accordingly, we will compare the permeability convex break-up of the building's ground floor with the visibility one to identify differences in their analyses. Initially, as figure 4c shows, the galleries numbered 9 and 18-20 are the most integrated ones, with gallery 20 illustrating the highest value of integration HH equal to 1.03. As in the axial permeability map the central part of the ground floor attracts the highest integration values acting as the core of movement between the old and the new extension. Simultaneously, their spatial configuration offers different movement choices, if we compare their position in the ring-type patterns as 'd' spaces (J-graph, figure 2a). This signifies that the exhibition areas are organized in a modular and flexible manner, enhancing circular exploratory movement for the people who have the option to choose between different paths.

If we move on to the analysis of the visibility convex break-up the differences in the integration values are noticeable in relation to the permeability map. The atria are included in the analysis and attract the highest integration values. Specifically, the atrium C presents the highest integration of 3.78 with the atrium A being the second integrator with a value of 3.54 (figure 4d). Thereafter, the gallery 18 located at the centre of the western axis is picked out with an integration value of 3.50 and the orientation gallery (9) adjacent to the atrium A (integration HH=3.42). The analysis clearly shows that in terms of visibility the atria A and C, which also offer vertical movement, are located in strategic positions within the museum's layout opening up the structure for the visitors to explore visually and orientate themselves.

Moving on to the next part of the syntactic analysis, we will describe how the visibility graph analyses (VGA) in terms of permeability and visibility can capture the spatial attributes of the museum. Knee-level visibility analysis is applied to visualize permeability based on visibility graph analysis. VGA analysis of the layout without the atria shows that integration is distributed along the intersection points of the front to back axes with those running along the east-west direction. The most integrated areas are gathered along the western axis of the Ashmolean along a sequence of intersections. Visual relations are enhanced when in the next diagram (figure 6b) the atria are included in the VGA analysis. Including the atria in the analysis we see that they draw integration to themselves. However, although they are amongst the most integrated parts of the museum, integration is still distributed along the western axis of the museum. Moreover, the entrance is also integrated, strengthening the capability of the entrance space to offer orientation in terms of the global patterns of integration to visitors on entering the building. The rich cross-visibility from and around the atria strengthens the probabilities for visual encounters among visitors who stand or move around them. The glass facades provide open and wide views to the rest of the galleries which have an impact on the overall visibility values of the voids. Comparing these two analyses, it seems that the high integration values concentrate inside the space of the atria where the vistas penetrate through them interlinking the surrounding galleries.

Furthermore, the visual relations in the building and the atria advance the notion of the building acting as a dynamic field of intersecting cultures over time, as the galleries' initial organization was done by the museum. If we focus upon eye-level integration, we see that the main axes are brought out. The topological structure of visibility picks up the geometrical structure of the building showing that the architects intuitively grasp how to use geometry in order to enhance navigation in the building. Furthermore, the atria affect the integration values around them creating a strong core which surrounds the main body of the ground floor and dominate the experience when people move throughout the museum. By comparing the VGA to the axial and convex analysis in terms of permeability and visibility values we realise that in the latter (figure 6a, 6b) the integration is overall higher, showing that the atria enhance not only the values around them but also on the whole ground floor. Separately, the atrium A presents the highest visual integration, in comparison to the atria B and C, strengthening its role as an important visual core in the museum's layout.

As the analysis of paths, which follows, will show, people who enter the museum and come across this extensive field of vistas, choose different paths for their navigation and re-encounter each other as they progress through the galleries. Also, the more they move further into the deepest parts of the museum the more opportunities for exploration appear. Most importantly though, when they reach the atria their degree of visual field expands (3a, bottom left image, 3b) so they get a panoramic view of the majority of the surrounding spaces across the floors, in two and three dimensions. The isovists analysis in the previous section proved that the atria and their surrounding galleries are strongly interlinked with varying degrees of connections.

Figure 5: (a) VGA analysis of the ground floor illustrating accessibility, (b) VGA analysis of the ground floor illustrating visibility

permeability analysis	Mean Integration HH	atrium A	atrium B	atrium C	ground floor
axial	atrium	-	-	-	
	surrounding spaces	1.80	1.66	1.78	
	Mean Integration HH				1.37
convex	atrium	-	-	-	
	surrounding spaces	0.82	0.84	0.71	
	Mean integration HH				0.68
VGA	atrium	-	-	-	
	surrounding spaces	6.05	6.28	6.22	
	Mean integration HH				5.90

visibility analysis	Mean Integration HH	atrium A	atrium B	atrium C	ground floor
axial	atrium	2.62	2.80	2.80	
	surrounding spaces	2.14	2.38	2.64	
	Mean Integration HH				1.85
convex	atrium	3.55	2.61	2.35	
	surrounding spaces	2.66	2.47	2.55	
	Mean integration HH				2.13
VGA	atrium	8.72	7.71	8.50	
	surrounding spaces	7.91	7.95	8.50	
	Mean integration HH				7.12

Figure 6: (a) Table showing the different integration values HH in the permeability analysis, (b) table showing the different integration values HH in the visibility analysis.

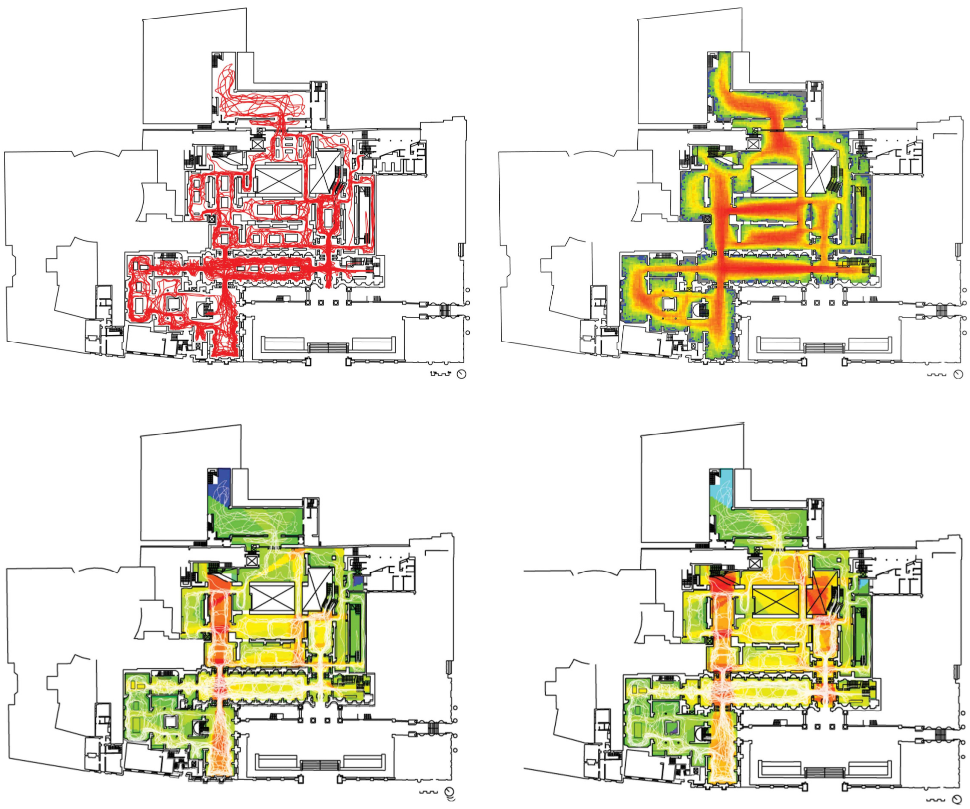
5a. Navigation routes

In the next section we will present how the spatial configuration of the Ashmolean's ground floor affects and structures navigation patterns and movement flows for its visitors. Previous studies in museum studies analyzing the physical aspects of galleries showed that these spaces influence visitors' navigation and movement (Bitgood 1994, Psarra 2005, Psarra et al. 2007, Yoshioka 1942, Tzortzi, Peponis, etc). Initially, it would be useful to focus on the analysis of two key points; firstly the circulation pattern which is created by the spatial layout; and secondly the architects' design intention to draw people into the core of the museum, simultaneously examining the effect the third dimension has on their navigation. In order to examine these points an observation study was conducted on three weekdays that included 50 people moving around the building for the first hour of their visit. Once they changed level they were dropped in order to focus on the way the ground floor dictated their movement. The mean movement rate, as observed, for all galleries on the ground floor was 24.6 minutes.

There is no prescribed way for people to navigate in the galleries but the space is configured in a way that allows many different diversions in their paths. The exercise showed that each visitor followed a different route exploring the various route possibilities the museum offered. At the aggregate level though, regardless of the variety of paths, a clear navigation pattern emerges as shown in Figure 7a. The majority of the observants were elderly people (36%), young families with children (28%), middle-aged visitors (24%) and young people (12%). As an overall finding we notice that the higher movement rates (figure 7a) are shown on the main and western axes both intersecting at the entrance. Half of the people used the Cockerell's axis upon entering the museum, 48% of them occupied the main one reaching the atrium A and only 2% turned right to the info desk. From the 50% of the ones who used the Cockerell axis, their movement thereafter is distributed along the western axis of the museum. By superimposing the VGA analysis with the observed traces (figure 7c, 7d) we realise that VGA analyses, with the main and the western axes highlighted, show similar patterns with peoples' movement patterns. Also, the lowest movement rates are found at the galleries which are located at the end of a sequence or at the deepest part of the configuration not being directly connected to the museum's axes (galleries 14, 17, 11, 12, 24, 23). They are also segregated in terms of their permeability and visibility values (figure 7c, 7d).

The spatial behaviour of visitors and especially their paths of exploration highlight a movement pattern which is directly affected by the spatial configuration of the museum. The atria with their strategic position in the spatial layout of the museum seem to attract peoples' activity towards and around them. The main axis leading to the atrium A enhances higher movement rates, in comparison to the atrium C which is located at the far end of the western axis and presents relatively low values. However, the fact that the Ashmolean presents various route choices that people can follow creates a feeling of unexpectedness and excitement in their navigation process and discovery of the museum's spaces.

As the discussion of the observation study shows the varying configuration, location and relational positioning of the atria voids in the layout creates different patterns. Out of the 50 visitors who were tracked, more than half of them (56%) reached the atrium A within the first hour of their movement. The rest of them remained in the galleries exploring the various exhibition sequences which are laid out at the museum. The observation study recorded the percentages of people who looked up, down or through the atria spaces to the neighboring areas or different floors in order to capture whether the three dimensionality of the voids plays an important role in their navigation and spatial cognition. The observations showed that 44% (22 out of 50) of people used the third dimension, shown by their head movement, to look from within the atria to the visually interconnected floors of the Ashmolean. Their movement after browsing the third dimension diverged accordingly but by overlooking from the atria they acquired a three dimensional overview of the building's height due to the great amount of visibility views it offers with the glass facades and internal structure. The rest of the people (56%), who did not look from the atria, used them as through route choices either to move on deeper in the museum's layout or to change floor level.



No of gallery	Integration (HH)	No of traces
9	6.64	24
10	5.87	12
11	4.7	8
12	4.92	4
13	5.79	10
14	4.23	8
15	5.54	9
16	8.16	15
17	5.65	7
18	7.54	17
19	6.66	10
20	6.73	15
21	6.66	25
22	7.02	27
23	5.06	19
24	4.99	17
25	5.39	18
26	5.71	19
27	5.77	21

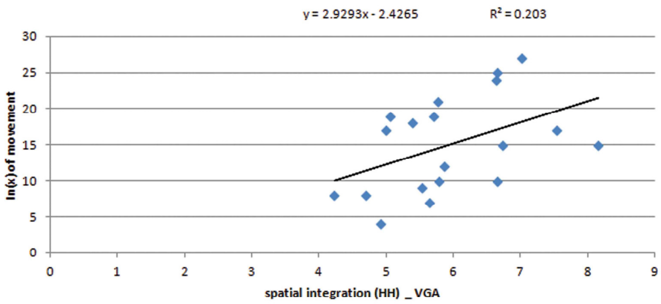


Figure 7: (a) The paths of 50 people observed for the first hour of their visit on the ground floor of the Ashmolean, (b) trails from 50 agents moving through the galleries. Red colored areas have high counts and blue colored ones have low counts, (c) VGA accessibility analysis superimposed with the traces, (d) VGA visibility analysis superimposed with the traces, (e) table and graph showing the correlation between the VGA accessibility spatial integration with the number of people passing through each gallery.

From the people who reached the atrium A, 39% of them ascended floor, 21% descended through the staircases, 32% remained in the same floor and the rest used the eastern lift. In total 60% of the visitors appropriated the stairs, showing that the third dimension combined with the open vistas offered from the atrium A (figure 3) enhanced their choice to change floor rather than remain in the same one. The voids disperse movement flows around them once people approach and embrace them in their navigation. It is the two-dimensionality of space that draws them deeper into the museum but when they reach the atria the third dimension opens up as an additional layer of visual information. A very significant finding from the observations shows that 64% of the people who reached the atrium A approached it in 10 min upon entering the building, showing that this space attracts them towards it. The atrium B was approached within 10 min only by 6% and the atrium C by none. The performance of the atrium C was quite low with only 2% reaching it in the one hour of observations and none of them using it in its vertical dimension, although it is well integrated in the plan (figure 6).

Figure 7(e) illustrates the relationship between the spatial information provided by the VGA analysis with the observation study of space use and movement to investigate their degree of correlation. This can be shown in the scattergram where the integration numerical values are correlated with the number of moving visitors within and through the galleries. Each blue colored dot in the scattergram represents one of the galleries of the ground floor, with their horizontal position showing their integration values and their vertical position illustrating the rate of movement they attract. The correlation connects the two variables and the line of best fit through the points describes the strength of the relationship. In the present case their correlation is positive with the R-squared value nearly being 20% (yet not so significant which might be because of the small number of traces observed up to this point). On the other hand though this might signify that there is an additional parameter to the two-dimensional analysis, which is the third dimension that affects peoples' navigation.

To conclude, it seems that every atrium illustrates different usage patterns although they all offer extensive vistas to their surrounding spaces and are highly integrated. Except from the two-dimensional approach, there is also the third dimension which indicates it as additional element to peoples' spatial behaviour explaining why visually high integrated spaces do not show high occupancy rates. It is under research and question how this information can be visualized and studied in order to explicitly show how the three atria affect peoples' navigation and spatial cognition. By focusing upon any diversions in visitors' path choices we realize that their paths split at junctions where the vistas offer a lot of information not only in two but also in three dimensions. In order to come closer to the goal of the study, we will compare peoples' traces with agents' movement in the next part of the paper.

5b. Agent-based simulation analysis

In this section we will present the agent-based pedestrian model, which has been simulated for the ground floor of the Ashmolean. The agent analysis is broadly used by space syntax researchers in order to visualize and predict how people navigate in the built environment. As Penn and Turner (2001) propose 'space syntax methods were developed in order to allow architectural space to be represented and its pattern properties quantified so that comparisons could be made between differently designed buildings or urban areas'.

For the purpose of the analysis 50 agents were released in the system with each one of them having a visual field of 170 degrees and every 3 steps changing direction in his movement. By applying the agent analysis on the plan we figure out that the majority concentrates movement at the front part and the highly integrated spaces of the museum (figure 7a, 7b). Specifically, high values are noticed at the central part of the building, which are the galleries included by the main axes designed by the architects (figure 1). Another area that presents high movement rates is the gallery 13 located at the northern part of the museum. The atria show relatively low values around them and being cut off from the main navigation routes followed by the agents. They are perceived as big barriers in their movement a fact which contradicts with the findings from the syntactic visibility analysis, characterizing them as gravitation spaces.

If we look at the points where the agents' traces divert and compare them with peoples' movement patterns we could find similarities and differences in their route choices. The spatial configuration of the ground floor affects them in ways which illustrate the fact that the configurational properties of space affect them in similarly same directions. There is a difference though in the concentration of flows around the atrium A which according to Figure 7(a) and (b) doesn't show the same amount of agents using the main axis to reach the atrium A. That could explain and support the hypothesis that the three- dimensionality of the atria attracts and influences visitors in their navigational processes and spatial cognition. The way the three-dimensional visibility intervenes in their perception of space is associated with the amount of people reaching the atrium A in reality compared to the amount of agents illustrated in the analysis which is lower.

6. Conclusion

This discussion leads us to some important conclusions regarding the questions set at the beginning of the paper. The permeability and visibility patterns analyzed separately, in terms of methodology, bring out different results explaining how the museum's layout affects and structures navigation and perception in two complementary ways. Visibility patterns enhance the structural coherence of the museum unifying the old with the new extension of the museum; proving that the architects' design intention to connect them strongly is realized. Moreover, special importance is given upon the comparison of the relation of these two systems since it captures the role of the third dimension in peoples' navigation. The design properties of the void spaces and their verticality within the museum's three dimensional configuration split visibility from permeability relations. In this manner therefore, the role of the third dimension, in spaces which are designed to create three-dimensional physical connections, is captured in a two-dimensional way which is expressed as the scope of the present research.

In general, it seems that the museum creates a sense of unity and continuity in its arrangement of the various galleries and spatial layout. The atria act as visual gravitation points that draw visitors to the deeper parts of the museum while strengthening its core. They also enhance peoples' orientation, exploration and circulatory movement, by offering visual information about the surrounding spaces strengthened by the third dimension, offering information about route choice. However, each atrium presents different usage patterns; the atrium A presents the highest concentration of people around it due to its configuration and open vistas to the rest of the spaces compared to atrium C which is well integrated but does not act as a reference point for peoples' navigation. Finally, the atrium B is used as a through-movement space offering rich visual connections thus assisting peoples' navigation and experience of the museum. Finally, the rich cross-visibility from the atria amplifies the possibilities for more visual encounters among the visitors enhancing the dynamic character of the museum.

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