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A comparative study of graph structures, traversability movement and exhibition strategy in museums during Covid-19

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ABSTRACT

The global pandemic of COVID-19 has posed challenges in relation to how buildings re-open to use, particularly buildings attracting large numbers of visitors, such as museums and galleries. As these institutions started to reopen across the UK and internationally, a number of social distance measures were adopted in order to safely bring people into their premises and access their collections. Building on Bill Hillier's theorical model of spatial types and spatial structures (2019), we explore the spatial-curatorial changes implicated in the re-opening of five British museums (The National Gallery, The Tate Britain, Tate Modern, British Museum and The Wallace Collection in London) and one American museum (The MoMA, New York). Our purpose is not to provide practical solutions, but to set the search for spatial approaches to the re-opening of museums within a theory of spatial structure in space syntax and inform the design future of public buildings. We present a model of a three-layered spatial system, interfacing the global and local structure of these buildings. We argue that the presence of intersecting cycles of movement in spatial layouts determines their capability for adapting to the one-way routes imposed by the pandemic. The spatial organisation of the display is a second factor influencing the reopening strategies, either limiting or optimising available spatial sequences to meet curatorial criteria.

KEYWORDS

Museums, Space types, Traversability, One-way route, COVID-19

1   INTRODUCTION

Despite placing many of their collections online (Agostino et.al 2020), museums around the world have to reopen during the pandemic due to social, educational and economic pressures.

One noticeable trend among museums is the growing emphasis curators place on the influence of space on visitors' movement patterns. Guidelines for the reopening of museums during the pandemic crisis specify instructions and interventions that are partly influenced by the spatial layout of buildings (Ellis and Szanto 2020). While strategies for virus-control, such as a limited number of entry tickets and fixed entrances and exits have been widely applied in museums around the world, British museums adopted one-way visiting routes in order to prevent people from reversing their paths crossing one another. This approach is barely seen in museums outside the UK. Figure 1 shows signages arranged in the National Gallery in London reminding visitors to follow the pre-assigned one-way routes. It is noticeable that museums in the UK have also adjusted the arrangement of one-way strategy accordingly because of the repeated changes of the pandemic condition. The Tate Britain, for instance, has experienced three significant spatial changes in its layout and exhibition arrangement over the recent two years.
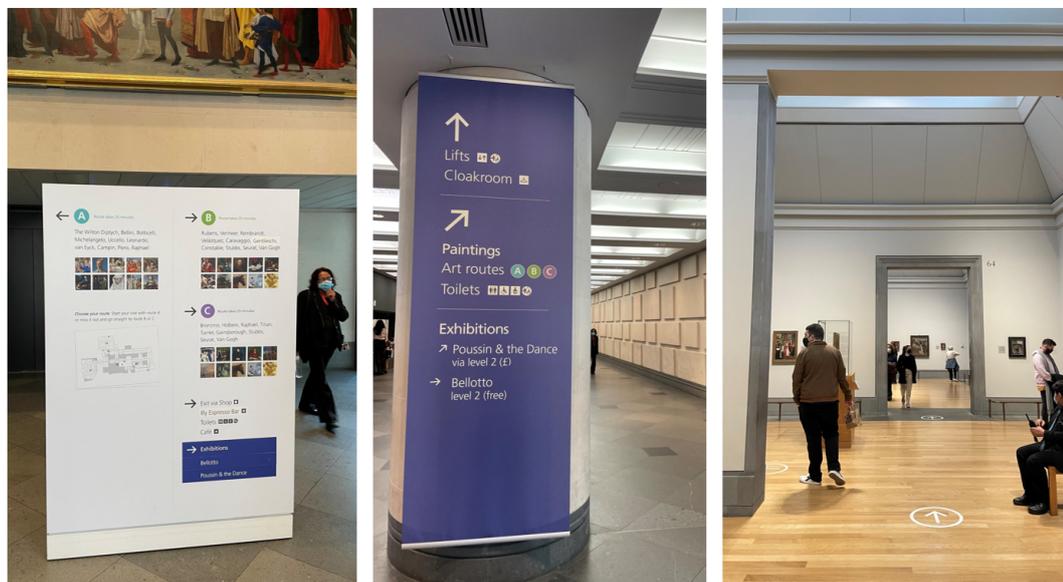

Figure 1: One-way route signages in the National Gallery

As the spread of pandemic remained poorly controlled, a situation that was accentuated with the new Omicron variant, the greatest challenge for curators worldwide is meeting requirements for safety without sacrificing the spatial, social, and educational experience. Most of the strategies used by museums concern practical solutions, specifying one-way circulation paths when distancing is possible and blocking of spaces in which social distance is not feasible. But we have no means of assessing the spatial and cultural effect of differences in the spatial structure of galleries, for example, the performance of a building as a whole in ways that makes it comparable to other buildings, including detecting relations of global performance. This paper sets out to provide a syntactic examination of selected museums in order to comparatively describe their structure as a way of making clear their relations to each other, and subsequently their relations to a family of possible structures or a model of spatial forms. In addition to this task, this study aims to answer the following questions: How does the original spatial layout of the selected museums affect the patterns of movement and circulation? What are the consequences of the

spatial changes and the museological narrative based on one -way route on the patterns of movement and spatial culture?

2   LITERATURE REVIEW

Hillier's classification of graph arrangements (1996) identifies four space types each one associated with the above paths: dead-ends (a-type of space without through-movement) (Figure 2a); trees (b-type of space allowing through-movement but only the same way back) (Figure 2b); cycles (c-type offering one alternative way back) (Figure 2c) and intersecting cycles (d-type offering more than one alternative path back) (Figure 2d). In his most recent research on graph arrangements (2019) he adjusted the definition of space types based on the number of spaces each space type is part of (from 1 to 4) and the number of through-movement connections from 0 to 3. He also explained that space types generate emergent graph structures, structure-types, which can contribute to the development of a theoretical and analytical model for comparing spatial structures. By analysing the Tate Britain, he argues that it has a d-structure almost in every part of the layout. By comparing London's and Tokyo's street networks, he suggests that Tokyo has a d-structure of main arteries generating routes from all parts to all others, whereas London forms c-structures linking the centre with sub-centres. In the case of buildings, a d-structure such as that of the Tate Britain in Milbank, constructs a dense pattern of convergence and divergence of routes, producing a high rate or encounters and re-encounters of visitors as they browse through galleries, or what is called the 'churning effect' (ibid.).
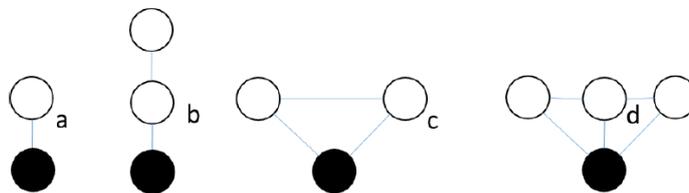

Figure 2: Space Types (Hillier 2019)

Extensive research using the space syntax method shows that, everything else being equal, there is a strong effect from the spatial structure and the distribution of integration-segregation on the patterns of movement and use in buildings, housing different institutional types, including museums and galleries (Hilllier et al, 1996; Choi, 1999; Huang, 2001; 2006; Hillier and Tzortzi, 2006; Koch and Stein 2012; Psarra 2009, Lazaridou and Psarra, 2015, 2017; Wineman and Peponis, 2010, Sailer and Penn, 2009). In a study of the Tate Britain, for example, strong correlations between spatial variables and data of human activity indicate a close relationship between the main circulation spine and the ways in which people move inside the building (Hillier et all, 1996; Tzortzi, 2007; Hillier and Tzortzi, 2006). The relationship between spatial configuration and the arrangement of displays using space syntax analysis also points to the key role space plays in organising collections through a synergistic relationship between spatial layout and display concept, structuring the museum visit (Peponis and Hedin, 1984; Psarra and Grajewski, 1999, Psarra et al 2007; 2009; Tzortzi, 2003; 2005; 2007; Stavroulaki and Peponis, 2003). Studies focusing on graph arrangements of layouts (Hillier and Tzortzi 2006; Capillé and

Psarra 2013, Lazaridou and Psarra, 2013, 2015) show that a- and d- spaces strengthen the integration levels of layouts, while b- and c- spaces increase segregation, by encouraging through-movement. Further, the balance of c-spaces and d-spaces is the crucial factor influencing navigation and experience of visitors. If c-spaces make the majority of spaces in a layout, visitors, and consequently social encounters, are constrained to particular sequences. On the other hand, visitors have more spatial choice and are exposed to a more probabilistic pattern of social encounters in layouts consisting of a high number of d-spaces (Hillier, 2019).

In his 2019 study of graph structures, Hillier defines the measure of 'traversability' closely related to 'Hamiltonicity', a property in which 'there is a path (Hamiltonian path) visiting each space exactly once, and so neither repeating or omitting nodes, and ending up where you started. Traversability can be measured for a structure-type by dividing the total number of steps, including revisits, required to go from each node to all others by the minimum possible for that number of nodes, that is, when each step take you to a new node (2019). The value of traversability will be maximised if there are no revisits in the sequence of viewing spaces, and minimised if all the spaces need to be revisited. Regarding the museums' one-way circulation strategy, calculation of traversability of museums' layout will help to examine their capacity to meet the requirements for safety without having to close a high number of exhibition spaces that compromises the cultural and educational experience. A reasonable hypothesis is that the higher the value of traversability the easier a layout would seem to adapt to one-way route transformations. But how is it possible to compare the structure of different museums? A detailed research approach is discussed in the next section.

3   DATASETS AND METHODS

Building on Psarra et al.'s work on the historical evolution of MoMA, New York, we first look at the newest expansion of the museum in 2019 and its previous layouts (Figure 3.1). We then investigate the reopening of the National Gallery, the Tate Britain, Tate Modern and British Museum in summer 2020, all of which have similar-sized layouts (Figure 3.2). A small museum of a private collection, The Wallace Collection, provides another interesting case, allowing a comparison between spatial structures of different sizes.
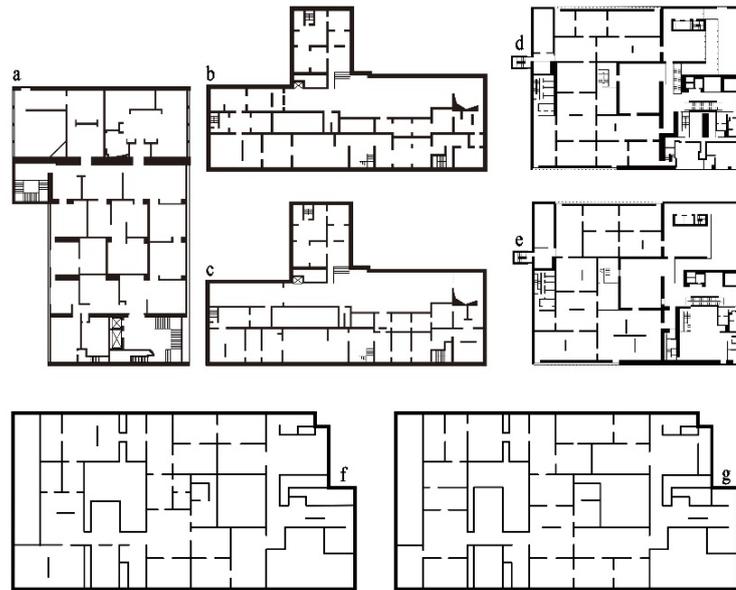
Figure 3.1: Floor plans of the MoMA. (a) 1967; (b) 1986; (c) 1996 ;(d) 2005 Fifth floor; (e) 2005 Forth floor; (f) 2019 Fourth floor ;(g) 2019 Fifth floor
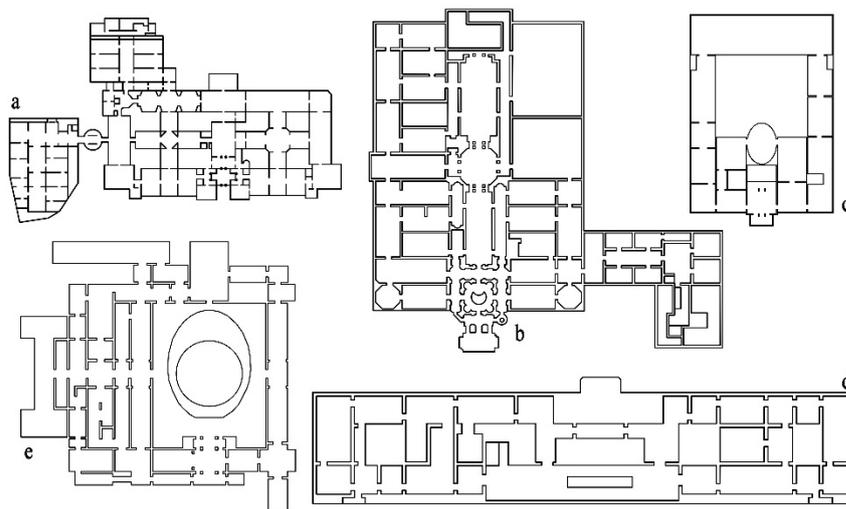

Figure 3.2: Floor plans of (a) the National Gallery; b) Tate Britain; (c) the Wallace Collection; (d) Tate Modern; (e) British Museum

4   RESULTS

4.1   The MoMA

In 2019 the Museum of Modern Art (MoMA) in New York opened its expanded campus developed by architects Diller Scofidio + Renfro, in collaboration with Gensler, adding more than 40,000 square feet of gallery spaces. Compared with the museum's previous layouts (Psarra et al, 2007; Psarra, 2009), we see that the intersecting cycles of movement provided in the 2005 expansion are reduced to two large intersecting cycles in the recent extension, largely defining linear routes (Figure 4.1). There are only two sub-cycles on the south side of the fifth floor while both floors have a considerable number of a-spaces, that is, dead-end rooms.
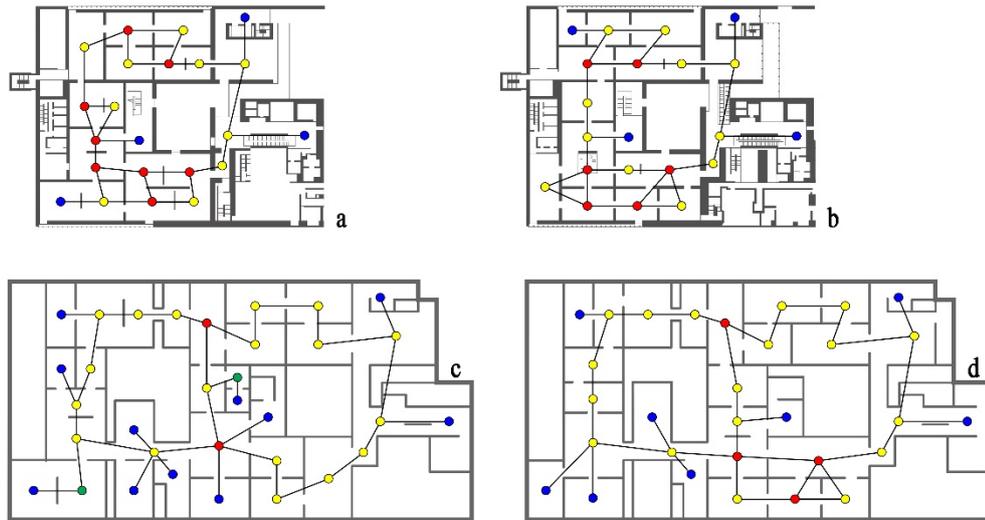
Figure 4.1: Unjustified graphs of the MoMA. (a) 2005 Fourth floor; (b) 2005 Fifth floor; (c) 2019 Fourth floor; (d) 2019 Fifth floor
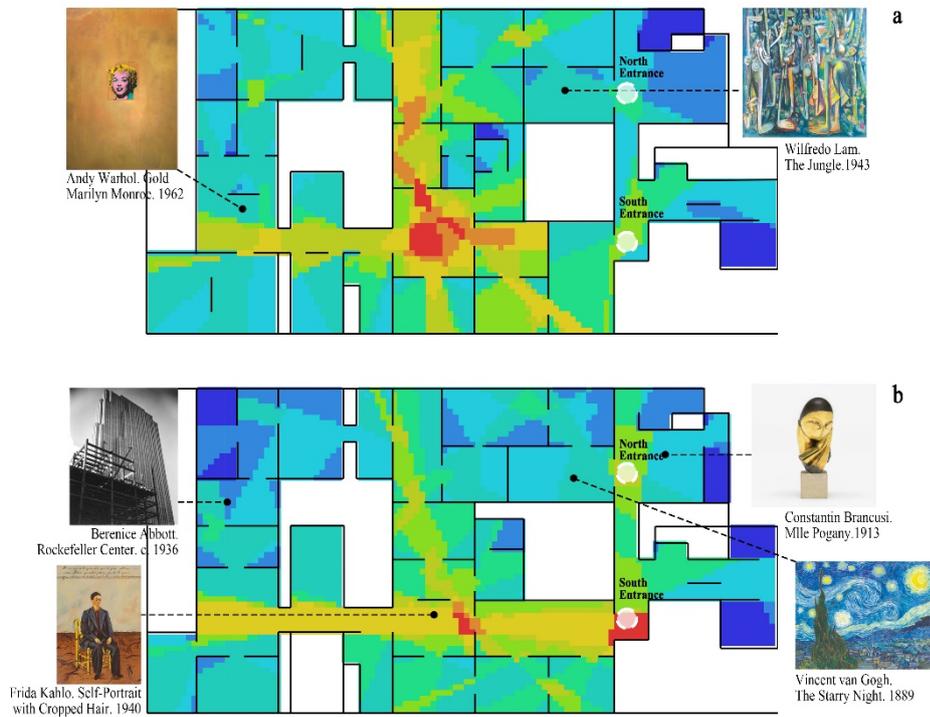

Figure 4.2: Visual integration of MoMA with target displays marked. (a) Fourth Floor; (b) Fifth floor

We see that on the fourth-floor integration (shown in warm colours) is mainly located at the centre of the layout, posing challenges for wayfinding and navigation, particularly on entering the galleries from the north and south entrances (Figure 4.2). On the fifth floor, integration connects the south entrance with the far west side of the layout. The galleries at the north and north-west remain strongly segregated on both floors (shown in cool colours). Popular displays recommended in the Museum map are placed either close to the north entrance or in the deepest

parts of the layout. The curatorial strategy is based on the attraction exercised by the exhibition content as in most areas the structure of circulation cannot guide exploration.

Table 1 shows the proportion of spatial types in relation to the total number of spaces and the measure of traversability in the different periods of the MoMA's design. We see that the proportion of d-spaces increases from 1967 to 2005 at 22% and 42% respectively but decreases drastically to 6% and 10% in the latest expansion. We suggest that the change in spatial types illustrates the evolution of the graph structure of the museum over the years, showing that with subsequent changes and extensions, it moved from linear sequence to a hybrid of linear and intersecting pathways finally reverting to the predominance of a linear path in the latest expansion. We then calculated traversability by simulating a visiting path that begins and ends at the same entrance while the path needs to cover the maximum possible number of exhibition rooms, after which the number of rooms visited was counted and compared with the total number of rooms (Figure 4.3). The results of the analysis of space types and traversability are shown in Table 1. The analysis shows that the measure of traversability follows a similar trajectory to that of d-spaces, first increasing (from 0.58 in 1967 to its highest value, 0.72/0.79 in 2005, on the 4th floor and 5th floor respectively), and then dropping to its lowest figure (0.59) in 2019.

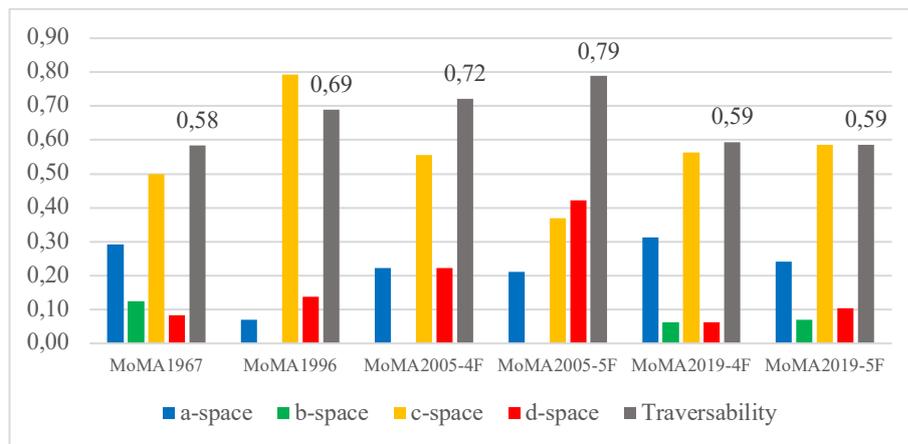Table 1: Space types and traversability value of the MoMA over time

Figure 4.3: Hamiltonian cycle of MoMA. (a) 1967; (b) 1986; (c) 1996; (d) 2005 Fifth floor; (e) 2005 Forth floor (f); 2019 Fourth floor; (g) 2019 Fifth floor

4.2   The National Gallery

Three one-way routes are used in the National Gallery after reopening in 2020, one in the Sainsbury Wing and two others in the main building (Figure 5.1). In order to minimise the number of rooms that need to be closed, the two one-way routes in the main building are interconnected along the central east-west axis. The entrance and exit are arranged so that people enter through the Sainsbury Wing on the left and exit through the main building. It should be noted that the National Gallery is the only museum this study has investigated that continues its one-way strategy since 2020, although the management has been less restricted since September 2021 due to the government's policy. Spaces that were blocked in the first reopening of the museum in 2020 are now fully opened at the time this paper is submitted (April 2022), while the three one-way routes remain unchanged and recommended to the museum visitors. The limitations on the entrances and exits remain the same till the current day. It should be noted that the analysis of this study regarding the reopening of British museums and galleries are mainly based on their first reopening in summer 2020.

Figure 5.1: (a) One-way routes in the National Gallery; (b) Blocked doorways and rooms (summer 2020) ;(c) entrances before + after the reopening (summer 2020).

In the Sainsbury's Wing, several doorways connecting the central spine of rooms with the galleries on either side were closed in the first reopening, reducing the levels of integration, the lateral spread of integrated connections (Figure 5.2) and the number of d-spaces (Figure 5.3). The one-way pathway (Figure 5.1a) required visitors to turn left immediately after entering the Wing and follow a linear route through segregated galleries to the front end of the layout (Figures 5.1a, 5.3b). They could then either cross to the west side and, following another set of segregated rooms, move in the opposite direction or return through the central galleries back to the entrance. The one-way route, thus, does not follow the structure of circulation with its lateral connections, taking people away from the most integrated areas, located at the centre of the plan, both at the beginning the end of the visit.
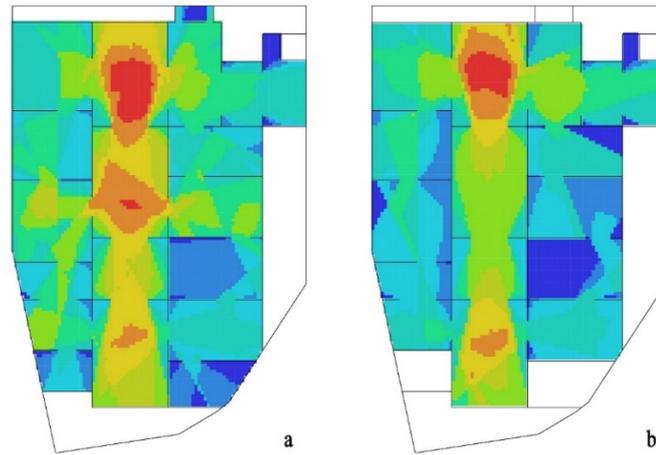
Figure 5.2: VGA of the Sainsbury Wing (a) before reopening; (b) during first reopening (summer 2020)
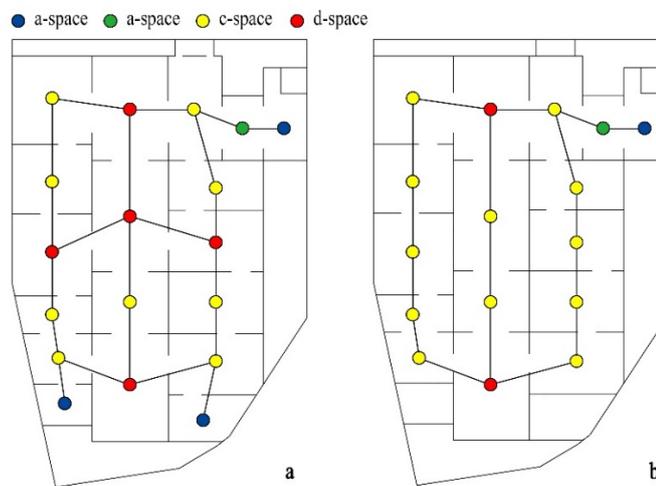

Figure 5.3: Unjustified graph of the Sainsbury Wing. (a) before reopening; (b) during first reopening (summer 2020)

The distribution of integration in the original layout of the main building of the National Gallery (Figure 5.4a) picks up the intersections of the enfilade axes, forming a grid-like pattern of main centres and sub-centres (shown in red and green respectively in Figure 5.5) that covers most spaces. There is a three-part structure consisting of the network of main centres, subsidiary centres and the rest of gallery rooms. The main centres are located on the central axis organising movement towards sub-centres which in turn connect with the local spaces (Figure 5.5).
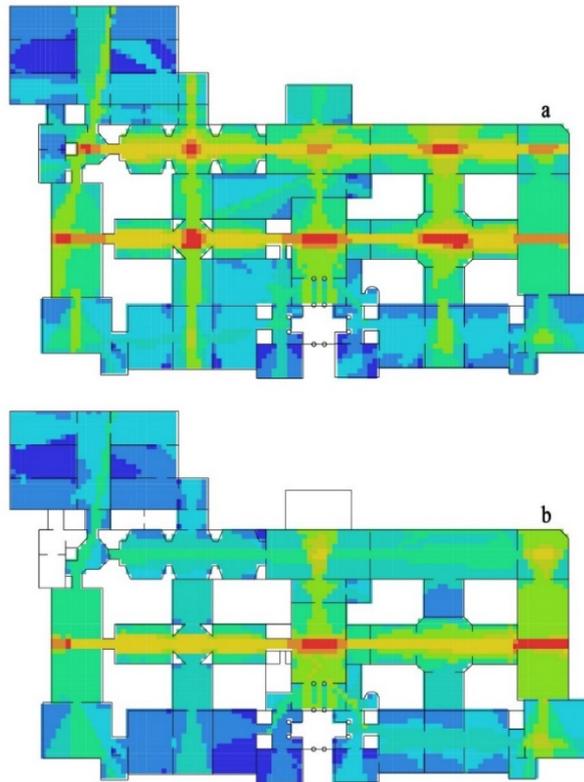
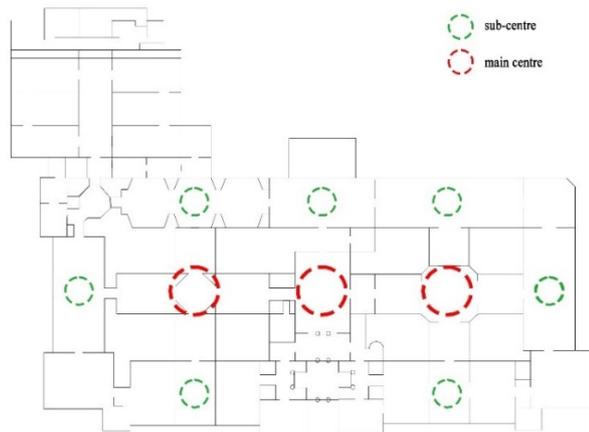Figure 5.4: VGA of the National Gallery's main building. (a) before reopening; (b) during first reopening

Figure 5.5: Main and sub-centres of the National Gallery's main building based on integration values

During the first reopening, the one-way strategy shortened the two axial links located on either side of the central axis of the building. As a result, the distribution of integration that previously traversed the gallery rooms in a grid-like pattern was limited to the east-west axis (Figure 5.4). The connections between the main centres and the sub-centres were thus cut by the blocked doorways. As the integration centres concentrate on the central east-west axis, there was also a considerable drop of the layout's intelligibility from 0.7024 to 0.5631 (R^2). The overall values of integration dropped as does intelligibility. The low levels of intelligibility in the National Gallery indicate that visitors were likely to find it difficult to navigate the building.

Comparing the graph structures before and after the first re-opening reveals a striking reduction of the proportion of d-spaces and a rise in the proportion of c-spaces from 47% to 72%, due to the blocked spatial links between exhibition rooms, as required by the gallery's one-way strategy, which turned a number of d-spaces into c-spaces. It should be noted that the Gallery blocked off four dead-end spaces for the reopening and created five new a-spaces which changed from c-spaces because of the cut of connections. In Figure 5.6c we show how we re-connected these five spaces with their adjacent galleries, so that the previous structure of d-spaces can be re-instated (while also keeping the dead-end spaces closed off). This structure is still flexible for one-way paths as we will show in a later section. In addition, it even increases the degree of intelligibility R^2 from 0.7024 to 0.7353 (R^2). Therefore, other things being equal and transmission rates taken into account, it might not be a good option for the National Gallery to change the spatial structure of the main building giving up the advantage it has by organising movement through the three-part network of centres.
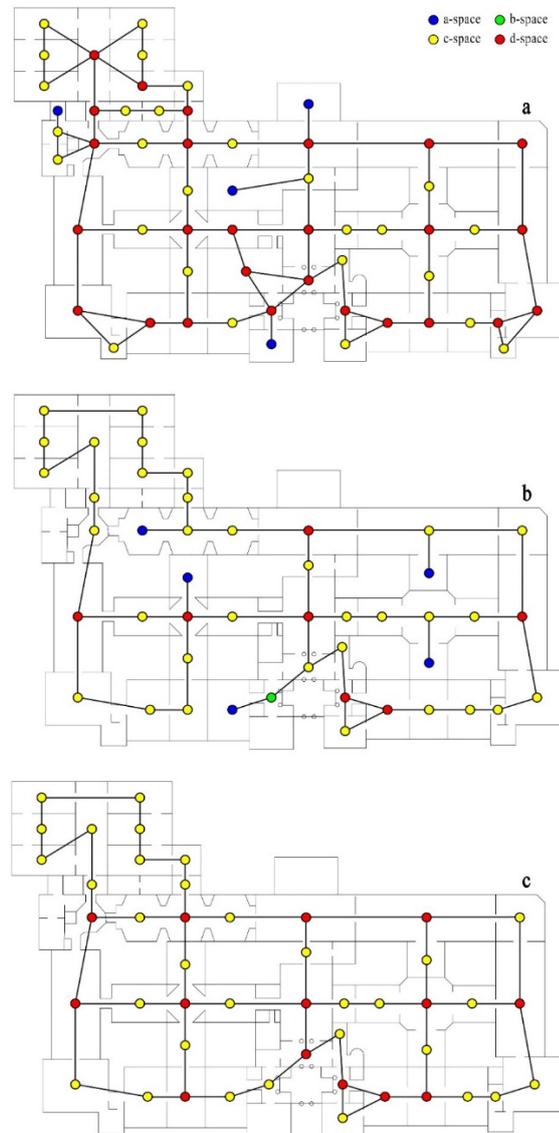

Figure 5.6: Unjustified graph of the National Gallery's main building, classifying spatial types by colour.
(a) before reopening; (b) first reopening (summer 2020); (c) the experiment

Is then the one-way strategy a global solution for all museums despite differences in their spatial structure? There could be more appropriate approaches for reopening, for the National Gallery at least. Based on the experiment in Figure 5.6c, one possible strategy is to divide the visiting route into multiple sub-cycles dynamically organised by d-spaces. Figure 6 shows a possible arrangement of visiting paths organised by main and sub-centres. While the main centre in the middle of the layout serves as the conjunction of the two one-way cycles (red), sub-centres divide the cycles into sub-cycles (green). The movement direction in sub-cycle paths (green) could then be adjusted according to the congestion thereby dynamically dividing the crowd. Therefore, a hierarchical organisation system is set based on the spatial system, whereas the main centres globally organise movement cycles and sub-centres serve as local nodes sub-dividing movement paths. However, one weakness of this arrangement is that the display narrative will not be able to follow a historical sequence but tend to see a random mix of display themes.
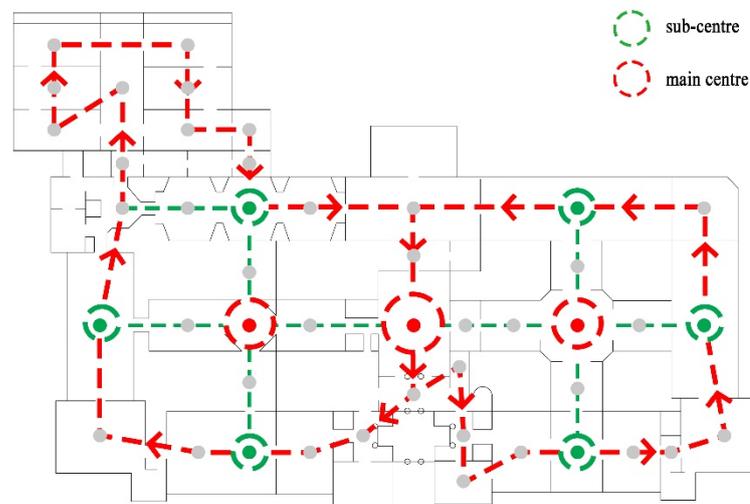

Figure 6: A experimental organisation of movement cycles based on the spatial system of the National Gallery's main building (main and sub-centres)

4.3   Tate Britain

During its first reopening in 2020, Tate Britain implemented a one-way strategy by offering two routes, departing from and returning to the main axis of the building (Figure 7.1). The exhibition themes along these routes, 'British Art 1540-1890' (top-left) and 'British Art 1930-now'(bottom-right), follow a clear chronological narrative. A high proportion of doorways were blocked, changing the spatial structure of the layout from a d-structure (intersecting cycles) throughout the plan (Hillier, 2019) to two locally applied c-structures (cycles) (Figure 7.1a, b). This strategy did not simply concern the application of safety measures but also consideration of exhibition strategies in the provision of routes. For example, in order to maintain the chronological sequence of the display in the bottom-right route, the curators have closed more spaces that those needed to create a Hamiltonian path, as seen in Figure 7.2. The 'British Art 1540-1890' route at the top left side of the plan was closed in October 2020, three months after the first reopening, with only the bottom-right part on the main floor remaining open to the public. Following the latest governmental policy in September 2021, which lifted the prevention

requirements in public buildings, Tate Britain abandoned its one-way strategy and opened most of the museum's spaces. However, some of the doorways remain blocked, retaining the curational design based on the chronological sequence of the two display routes. The central axis is now used for special exhibitions, while most of its connections with the west and east side are blocked (Figure 7.3c).
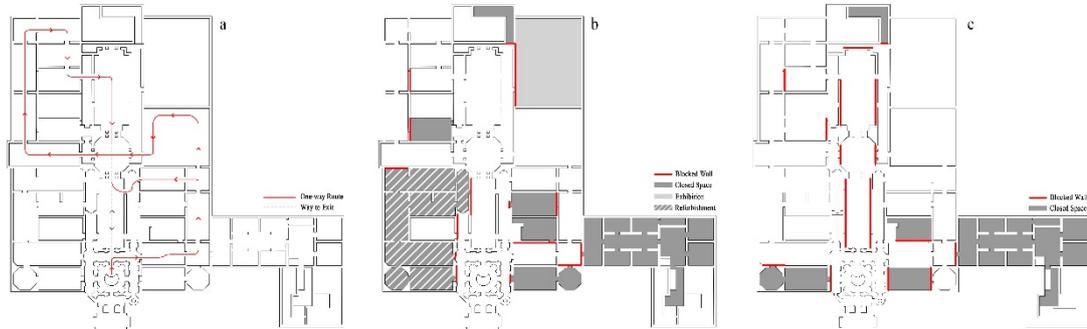

Figure 7.1: (a) One-way routes in Tate Britain during the first reopening; (b) Blocked doorways and rooms during the first reopening (summer 2020); (c) Currently blocked doorways and rooms
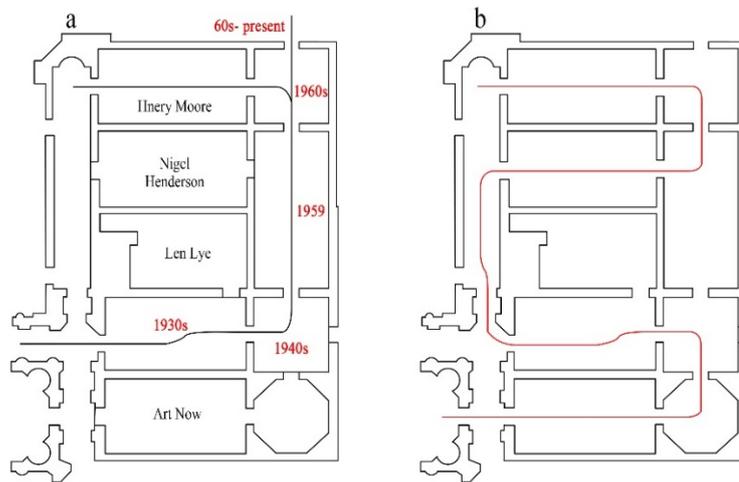

Figure 7.2: (a) The arrangement of displays in route 'British Art 1930-now'; (b) Ideal Hamiltonian path with only one room closed

Figure 7.3: Blocked connections between the central axis and the east side

Similarly to the main building of the National Gallery, the Tate Britain has a grid-like structure of integration centres consisting of a main integration centre that is located on axis and sub-centres found on the west, south and east sides of the building (Figure 7.4a). The one-way strategy for the first reopening changed this spatial structure to two c-type sequences that cover the main centres only. In terms of spatial types, like the National Gallery, the Tate Britain limited the number of d-spaces to those located on the main axis (Figure 7.5). Once visitors make a choice of route along this axis, they can only finish a sequence and get back to it. These changes illustrate that after reopening the Tate Britain comes close to Huang's model of modern museums with a 'deep integration core and strong sequence' (2006). Each sub-cycle in the Tate Britain is assigned a historical theme which is enhanced by the sequenced spaces. The style of the visiting experience thus, changes from one where the rings of circulation guide the encounter of the visitors with the artworks to one where a pre-decided sequence and educational message structure the visit, that is, from a spatially driven model to a conceptual model of exhibition. The blocked connections between the central axis and the two sides in the museum's latest spatial configuration have minimized the configurational function of the central axis. Spaces with high visual integration value are now concentrated at the entrance and the deepest part of the layout (Figure 7.4c). As a considerable number of d-spaces (red) change to c-spaces (yellow) (Figure 7.5c), it is clear that the spatial configuration of Tate Britain has transferred from d-structure to two c-structures connected in north and south ends.
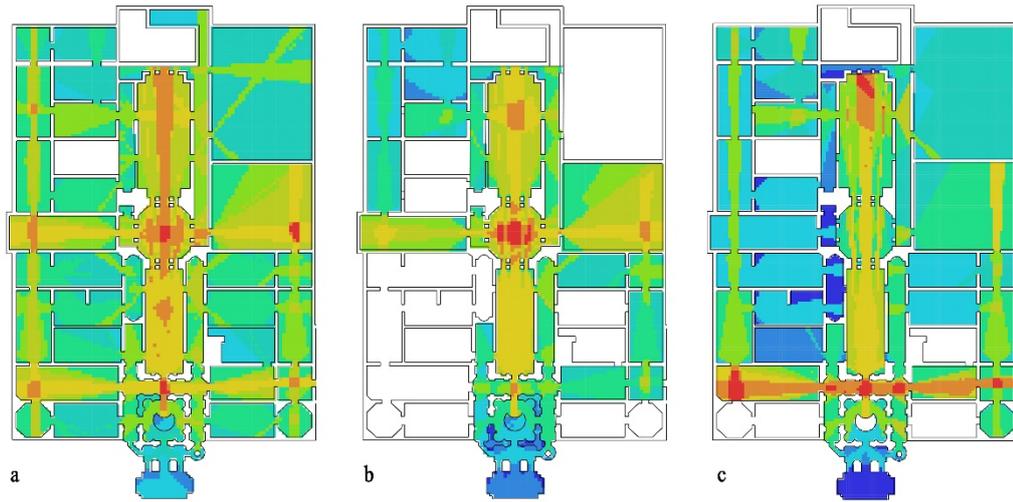
Figure 7.4: VGA of Tate Britain. (a) before reopening; (b) first reopening; (c) current
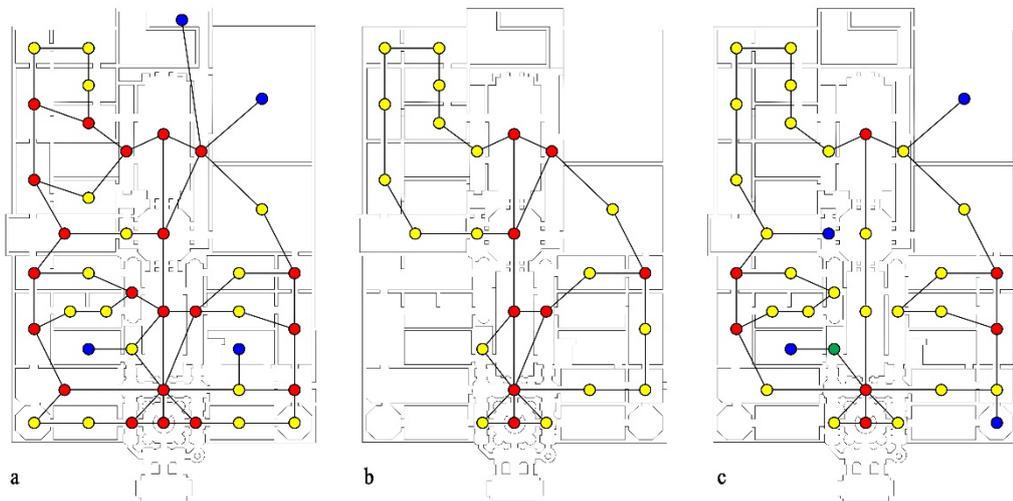

Figure 7.5: Unjustified graphs and space types. (a) before reopening; (b) first reopening; (c) current

4.4   Tate Modern

A lot of museums have put lines all over the floor and, you know, they kind of look like supermarkets. So what we've done at Tate Modern is its minimal signage and where it is you really have to follow it…… It is quite a clear message about how to negotiate the building. We found that our spaces are very suited to this kind of operation (Director of Tate Modern, Frances Morris, Interview with The Voice Newspaper, August 2020).

Compared to the National Gallery and the Tate Britain, the Tate Modern has introduced fewer changes for constructing a one-way circulation pattern. With a display that does not follow a historical narrative, Tate Modern has greater flexibility than other museums to alter the curatorial message by changing the visiting sequence. For example, the western display rooms are visited in

a reversed way than in the original plan during the museum's first reopening in the summer of 2020. (Figure 8.1). After the first reopening, the distribution of visual integration was not significantly different from that of the original layout, apart from the decreased integration values in the central and northern parts of the plan (Figure 8.2). Looking at the changes of spatial types, after applying the one-way strategy all spaces were c-spaces (Figure 8.3). In fact, among all the museums we investigated, the Tate Modern is the only one that has successfully achieved the Hamiltonian cycle in the sense that most spaces are covered in a one-direction path. Following the governmental policy, the Tate Modern reopened the rooms that were closed in the first reopening but the order of entrances and exits remains the same. This means visitors still need to enter the gallery from the east and exit from the west (Figure 8.4). In other words, Tate Modern keeps its one-way strategy even though the current government rules do not require it. It could be argued that the spatial configuration of the Tate Modern has best adapted to Covid-safety rules as it can satisfy the one-way strategy through minimal spatial changes without affecting the exhibition experience.

Figure 8.1: (a) One-way routes in Tate Modern (summer 2020); (b) blocked doorways and rooms
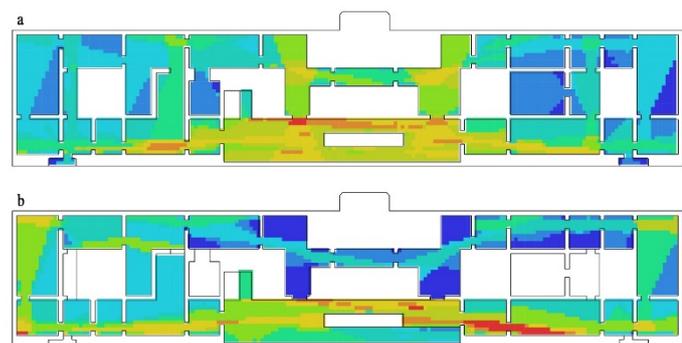

Figure 8.2: VGA of Tate Modern. (a) before reopening; (b) first reopening (summer 2020)
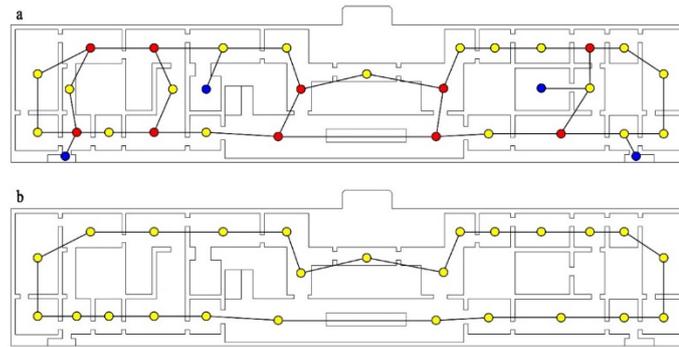
Figure 8.3: Unjustified graphs and space types. (a) before reopening; (b) first reopening

Figure 8.4: Signages in Tate Modern reminding the fixed entrances and one-way routes

4.5   British Museum

Like other London museums, the British Museum established a one-way strategy for the first reopening in summer 2020. The spatial organisation of the museum went back to its previous condition in September 2021 and remains as such until now. During its first reopening, a group of exhibition rooms on the west side were closed. Two one-direction routes connected by the central atrium were arranged to the west and east side of the building respectively (Figure 9.1).

Similarly to the main building of the National Gallery, the spatial configuration of the British Museum before the reopening presents a three-part structure consisting of the hierarchical network of main centres located in the central and northern horizontal axes, and sub-centres attached to the main centres, which then connect with local spaces (Figure 9.2a). However, in contrast to the one-way strategy applied in the National Gallery, only a few sub-centres in the British Museum were closed, in a way in which the main centres and sub-centres remained connected. Instead of losing spatial control from global to local, global organisational spaces - the 'main centres' - shifted from the horizontal axes to the central atrium. The spatial organisation of the building after the first reopening still followed the hierarchical system, in which some of the original main centres became sub-centres and previous sub-centres turned into local spaces (Figure 9.2b). Noticeably, the intelligibility value of the spatial layout increased from 0.4373 to

0.5854 (R²) after the first reopening. One hypothesis is that the atrium's organisational role was strengthened, as it has high visual integration value both in the layout before and after the reopening but is less important in the original network in organising movement flows. Figure 9.3b presents the museum's spatial configuration with several c-patterned cycles organised by the atrium.
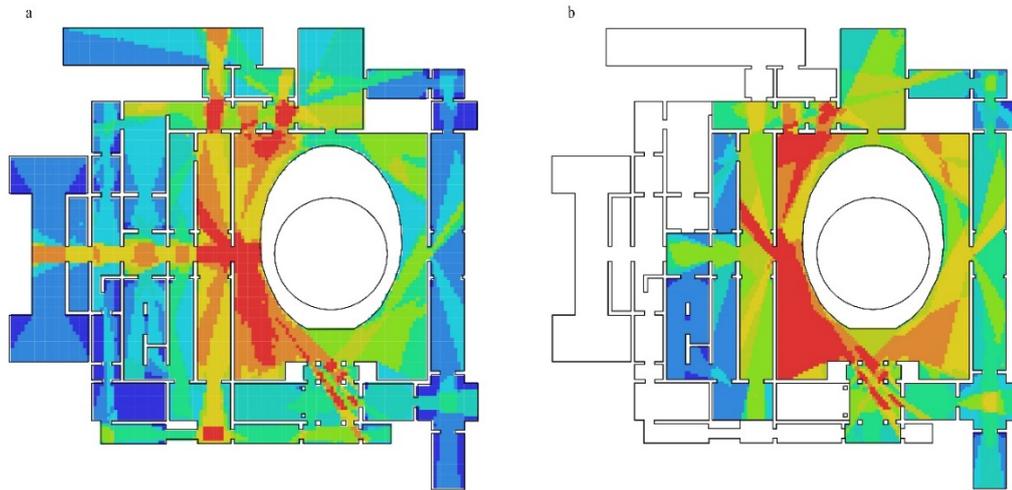

Figure 9.2: VGA of British Museum. (a) before reopening; (b) first reopening

Figure 9.3: Unjustified graphs and space types. (a) before reopening; (b) first reopening

4.6   The Wallace Collection

Previously owned by a private collector, the Wallace Collection is now a national museum exhibiting European collections from the 15th to the 19th century. The building is much smaller compared to the other buildings and has a large main sequence intersecting with an inner sub-cycle (Figure 10a). The museum closed only three spaces in its first reopening and assigned a single-directional path starting from the entrance and finishing at the exit in the west side (Figure 10b). As a consequence, the d-spaces before reopening were turned into c-spaces (Figure 10e, f). Due to the small size of the collection, displays are simply arranged by themes such as decorative arts, French paintings and furniture. Similar to the Tate Modern, the arrangement of displays in

the Wallace Collection does not follow any chronological narrative minimising the effect of the one-way route on visitors' experience.
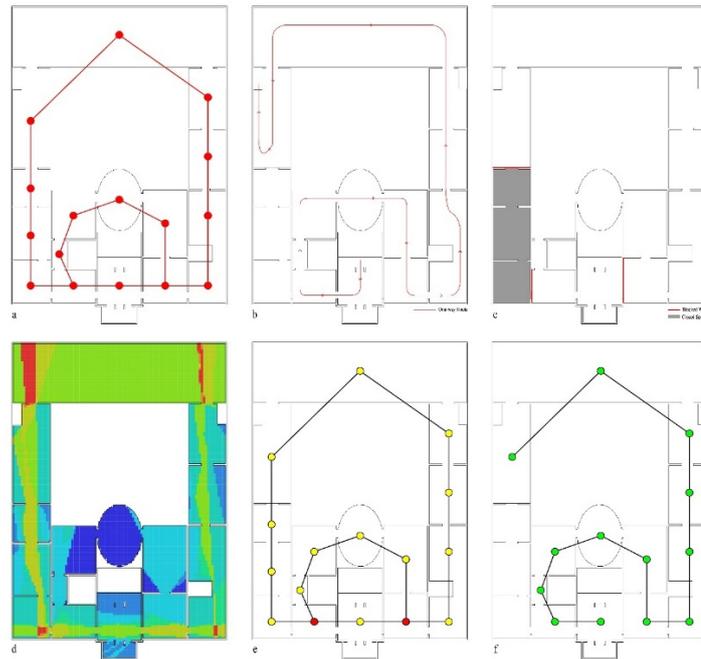

Figure 10: Analytical graphs of the Wallace Collection. (a) unjustified graph of initial layout; (b) one-way path during first reopening; (c) blocked doorways and rooms; (d) VGA before reopening; (e) spatial types before reopening; (f) spatial types during first reopening

4.7 Changes in the proportion of a, b, c, and d spaces of the investigated museums after reopening

Table 3 shows the comparison of changes in spatial types of museums after their reopening in the summer of 2020. Only Tate Modern and The Wallace Collection have fulfilled the one-way strategy among all the museums we investigated. That is, there are no alternative returns throughout the navigation inside the museum but only a one-direction route. While all spaces in Tate Modern turned into c-spaces, forming a one-direction cycle, spaces in The Wallace Collection turned into b spaces with a separate entrance and exit, generating a one-direction path. Except for the main building of the National Gallery, all the other museums managed to reduce the number of dead-end spaces (a-spaces). As a consequence of applying one-way strategies, there is a clear drop in the percentage of d-spaces with an increase of c-spaces. Compared with the National Gallery and Tate Britain, the British Museum sees fewer changes in its spatial types. For the reason that it only closed spaces in its edge area while not blocking the spatial connections between rooms that remained open.

Table 3: Changes in the percentage of a, b, c, and d spaces of the investigated museums after reopening in the summer of 2020

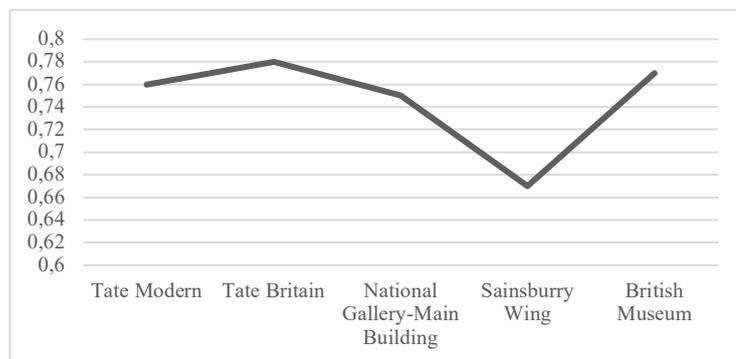## 4.8 Traversability of the investigated museums

Traversability is a crucial property of layouts for its close connection with the Hamiltonian path where in its highest values it allows visiting as many gallery spaces as possible and omitting as few rooms as possible. Hillier has associated the c-type and d-type structure with high values of traversability and Hamiltonicity (2019), as opposed to the a-type and b-type of structure that have the lowest traversability values. Here we test this model with the layouts of the museums before and after *reopening and* evaluate their strategy of circulation based on the capacity of the spatial structure to provide the closest to the ideal Hamiltonian path. The Wallace Collection is not included in the comparison as the size of this museum is smaller than the others. Table *2* presents the traversability value of the five British museums before the pandemic. Despite their differences in terms of spatial properties and exhibition themes, most of the museums have similar traversability value between 0.75-0.78. The Tate Britain has the highest traversability value among all layouts, with only 22% of spaces closed for the Hamiltonian path.

The analysis results show that layouts with a higher proportion of d-spaces over the total number of spaces in the layout tend to have the highest traversability values (R^2=0.8359), confirming Hillier's proposal about d-structures possessing high levels of traversability. In contrast to Hillier's model about c-spaces, the correlation between the proportion of c-spaces and traversability values is weak (R^2=0.1889). Based on the suggestion that the balance between c-spaces and d-spaces is the crucial factor influencing visiting experience (Hillier and Tzortzi, 2006), we calculated the ratio of the number of c-spaces to d-spaces and find that there is a high negative correlation with traversability (R^2=0.8371). In other words, the higher the number of d-spaces compared to c-spaces, the better museums can adjust to a Hamiltonian path, and to the one-way strategy. It is noted that this is a preliminary study and more cases should be added to the sample for a statistically reliable result. Also, apart from Hamiltonian cycle, organising one-direction paths with fixed entrances and exits is also a possible solution for certain museums to apply one-way strategy. However, it provides the first test of Hillier's theoretical model in the 2019 paper.

Does this result illustrate that as long as museums increase the interconnectivity of spaces, they can get better levels of traversability? In order to answer this question, we look at the correlation between the ratio of number of connections (doorways) to the number of nodes (spaces) within the layouts and traversability (Figure 27d). The weak correlation between the two variables (R^2=0.3395) suggests that simply enhancing spatial interconnectivity by opening more doorways does not lead to the increase of traversability value. It is rather the arrangement of d-spaces and their relation to the rest of the spaces that contributes to high traversability values. A detailed discussion is provided in the following session with a focus on the c- and d-structures in museums.

Table 2: Traversability of the British museums before reopening

5   DISCUSSIONS

5.1   Spatial structure and traversability

Hillier's suggestion that c- and d-structures have the highest levels of traversability at 1 (2019) means that in a spatial layout with a cyclical form or a grid form there is no need to close many connections between spaces in order to obtain a Hamiltonian path. Among the museums we have investigated, the fifth floor of the MoMA in its 2005 version and the Tate Britain have the highest levels of traversability at 0.79, and 0.78 respectively (Table1, Table 2). We suggest that while the 2005 MoMA illustrates how the spatial organization of a complex c-structure can have high levels of traversability, which has a hybrid of linear and intersecting pathways organised by d-spaces (Psarra et al, 2007; Psarra, 2009), the Tate Britain has higher levels of adaptability to strategies specifying more than one one-way route.

Psarra proposes (Psarra et all., 2007; Psarra, 2009) that the expansion of MoMA in 2005 expressed Alfred Bar's conceptual organisation of Modern Art as a dual trajectory (the 'rational' and 'intuitional' thematic lines) through the spatial arrangement which interconnects sub-cycles, which showcase the rational theme, with the main sequence, presenting the intuitional narrative line. Sub-cycles are locally organised by d-spaces enabling visitors to take a detour from and return to the main sequence. As for the Tate Britain - the d-structured museum as defined by Hillier (ibid.) - a clear global network of d-spaces, consisting of centres and sub-centres, covers the whole layout with intervening c-spaces in between. In both buildings, d-spaces play an important role in constructing the global structure as well as connecting global-scale and local-scale movement. Appropriate numbers of d-spaces and their relational logic with c-spaces and the rest of the spaces in spatial design will not only give rise to social co-presence and encounter in the process of visiting, as Hillier suggests (Hillier, 2019), but also increase the adaptability of the layout to accommodating Hamiltonian paths.

5.2   Spatial system: a new perspective to understand the structure of graphs

The different implications of the one-way strategy in the British museums illustrate the importance of the spatial system in the reopening. Figure 11 shows a schematic diagram of the spatial structure of the National Gallery and Tate Britain before reopening. They both consists of a three-layered spatial system comprising a network of main centres (red) and sub-centres (pink) distributing movement to local spaces. However, the sub-centres in the National Gallery are situated between the main centres and the local spaces found in the periphery. In contrast, in the Tate Britain the main centres transfer movement to the sub-centres at the edges of the building. Since in the main building of the National Gallery the connections between its main centre and sub-centres are blocked, the relation between global-scale and local-scale movement is weakened. As a result, the spatial layout becomes less intelligible. On the other hand, in Tate Britain, although the change of sub-centres from d-spaces to c-spaces (Figure 7.5) means that

they lose their structural role in the system, the main centre retains its power in distributing movement since it has direct connections with local spaces.
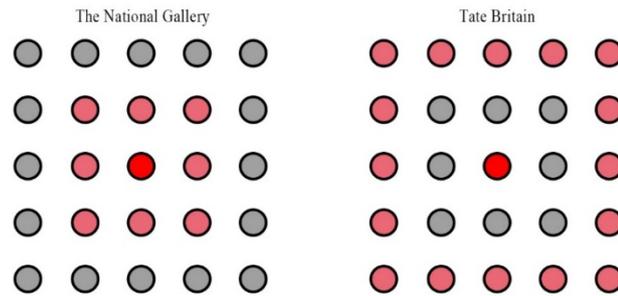

Figure 11: Schematic diagrams of the spatial structure of the National Gallery and Tate Britain before reopening

There are two limitations regarding the concept of spatial systems. One is the lack of systematic definition of the main centres and subcentres. One hypothesis is that there should be two ground rules defining the main centre: it must be one of the spaces with the highest visual integration value at radius n, while it should also be a d-space, as the main centre organises movement on the global scale. It is arguable whether all subcentres, the local organisers, should be d-spaces as well. Another limitation is the normalisation of VGA if we want to make a cross-comparison between a large number of museums in order to identify the hierarchy of integration values. Further study will focus on these questions.

5.3   The effect of the display arrangement

The curatorial intention about the exhibition arrangement in the British museums also plays an important role in the modification of spatial configuration in the reopening strategies. This study proposes that there are two curatorial factors that influence the architectural experience of museums and the spatial changes for reopening: whether the narrative has coherence (chronological, thematic or otherwise) and if the meaning of the display is pre-given. As suggested by museum scholars (Tzortzi, 2007; Psarra, 2009), the visitors' engagement with exhibitions is more likely to be varied in museums which encourage spatial exploration. Based on the six museums studied here, we argue that the original layout of the Tate Britain, the National Gallery, the British Museum and the 2005 layout of the MoMA provide visitors with potential for individual experience. On the other hand, the limited number of alternative sequences in the Tate Modern, the MoMA 2019 and the Sainsbury Wing construct an educational and aesthetic experience that is pre-given.

Although shifting to linear sequences with a chronological narrative after reopening, the Tate Britain and the main building of the National Gallery present different approaches to adapting to changes due to the pandemic. Chronological narratives have existed in Tate Britain before COVID-19 but were weakened by the spatial configuration which encouraged self-exploration.

As previously explained, the changes that happened in the Tate Britain are mainly directed by the chosen narratives of the exhibition sequences, since the museum blocks more spatial connections than a Hamiltonian cycle needs (Figure 7.2). The recent spatial layout of Tate Britain after cancelling the one-way strategy further illustrates a shift in the museum's curatorial intention: from individual exploration to pre-given meaning. On the other hand, having initially no sequenced narrative, the one-way routes in the National Gallery's main building creates new narratives.

5.4   A dynamic strategy instead of one-way circulation

There might be alternative solutions to the one-way strategy that British museums are applying, controlling congestion through curatorial and technological interventions on route choices. The National Gallery's main building for instance, is expected to have a more intelligible organization of movement patterns if its spatial interconnectivity is not weakened and visitors are guided by a dynamic minimal system of instructions provided through audio-equipment or signage in the main centres and sub-centres. The organisation of visiting routes of British Museum during its first reopening presents a similar case, which used its main atrium to organise sub-cycles attached to it. This study suggests that the distribution of d-spaces inside the layout and the connection between global and local spatial network are the two factors that determine whether the spatial configuration of museums is able to accommodate such dynamic strategy. Even in the future when social distancing might no longer be important, the joint operation of spatial configuration and curatorial interventions, such as customised visiting routes and defining no-go zones where the density of people has reached the top line, will still contribute to improving over-crowdedness and other potentially undesirable situations (Seo and Ahn, 2010; Yoshimura et al., 2014; Tsiropoulou et al., 2017).

5.5   The spatial culture of art museums in post-COVID-19

It is arguable whether the relationship between museums and visitors is going to have a permanent change because of the pandemic. However, the responses of the five British museums reflect in some sense Huang's proposal that the role of museums is gradually transforming from educational to commercial and experiential environments. The powerful spatial control at the global level and the strong sequences with pre-given meaning in the current layout of the Tate Britain provide visitors with an experience that has been pre-structured before they even begin their exploration inside the building. While museums are changing both spatially and curatorially, visitors are likely to be more knowledgeable as well, since virtual museums are recently becoming popular and people can explore them online before they pay the actual visit. Whether the museums will be the 'machine of showing art' (Serota, 1995) or 'civil education authorities' (Hulten, 1974), it is necessary for curators to understand the transformation of spatial cultures in terms of the new spatial-curatorial arrangements and the new attitudes of the visiting public.

6 CONCLUSIONS

This study has investigated the influence that the outbreak of COVID-19 has brought on five British museums and American museum. While the spatial effect on movement patterns has been emphasized by curators around the world for the control of the virus transmission, British museums chose the one-way circulation strategy for their reopening. Based on the findings from the analysis of spatial changes in these museums, a spatial-curatorial evaluation system is proposed for examining the current reopening approaches and the likely effects to the future spatial design of museums.

The study has provided a first test of Hillier's comparative model of spatial structures, confirming that d-structures achieve high levels of traversability. The d-structure is the determinant factor that not only influences spatial exploration and navigation, but also plays an important role in the social and aesthetic construction of meaning alongside the exhibition arrangement. We have found that museums with d-structures such as the National Gallery and the Tate Britain consist of a grid-like system of main centres and sub-centres that distributes movement to the local spaces. Similarly to the dual-network of urban streets (Hillier, 2003), we propose that there is also a dual-, sometimes three-layered, network in the spatial layout of museums. While the d-structure serves as the foreground system and the c-, b- and a- spaces as the local system, the way in which global and local structures interconnect with each other affects the exploration patterns of visitors and the adaptability of museums to restrictions introduced by the pandemic. Associated with spatial properties, the display narrative also carries the potential to affect the organisation of routes limiting or optimising the available sequences to define the spatial, educational and aesthetic experience. Different from Hillier's approach that focuses only on the spatial structure of the Tate Britain for the generation of social encounters, this study argues that what really matters is the cooperation between curatorial approaches to narrative and spatial networks.

REFERENCES

Agostino, D., Arnaboldi, M. and Lema, M.D., 2020. 'New development: COVID-19 as an accelerator of digital transformation in public service delivery'. *Public Money & Management*, pp.1-4.

Capillé, C. and Psarra, S., 2014. 'Space and planned informality: Strong and weak programme categorisation in public learning environments.' *A/Z ITU Journal of the Faculty of Architecture*, 11(2), pp.9-29.

Choi, Y.K., 1999. 'The morphology of exploration and encounter in museum layouts.' *Environment and Planning B: Planning and Design*, *26*(2), pp.241-250.

Hillier, B., 1996. *Space is the machine*. Cambridge: Cambridge University Press.

Hillier, B., 2019, July. 'Structure or: Does Space Syntax Need to Radically Extend Its Theory of Spatial Configuration?.' In *Proceedings of the 12th International Space Syntax Symposium*. Beijing JiaoTong University, Beijing (pp.0).

Hillier, B. and Hanson, J., 1989. *The social logic of space*. Cambridge: Cambridge University press.

Hillier, B. and Tzortzi, K., 2006. Space syntax: the language of museum space. Mc Donald, S. (ed.) *A companion to museum studies*, Malden MA: Blackwell, pp.282-301.

Hillier, B., Major, M.D., Desyllas, J., Karimi, K., Campos, B. and Stonor, T., 1996. 'Tate Gallery, Millbank: A study of the existing layout and new masterplan proposal.' *Technical report, Bartlett School of Graduate Studies*, University College London, London.

Honey-Roses, J., Anguelovski, I., Bohigas, J., Chireh, V., Daher, C., Konijnendijk, C., Litt, J., Mawani, V., McCall, M., Orellana, A. and Oscilowicz, E., 2020. 'The impact of COVID-19 on public space: a review of the emerging questions.' [online]. Available at: https://osf.io/rf7xa/ (Accessed: 22 September 2020).

Huang, H., 2001, May. 'The spatialization of knowledge and social relationships.' In *Proceedings of the Third International Space Syntax Symposium*, Georgia Institute of Technology. Atlanta GA (pp. 43-1).

Huang, H., 2006, July., 'The embodiment of the social roles of modern museums-A study on the space and body in the modern museums.' In *International Committee for Museum Management 2006 Symposium*, Chinese Association of Museums, Beijing.

Hulten, P., 1974. 'Beaubourg et son musée où explosera la vie [Beaubourg and Its Museum Where Life Will Explode].' *Réalités*, no. 337.

Koch, D., Stein, J. (2012), 'Decomposing Programmes-Recoding Hospital Work with Spatially Syntactic Information', 8th ISS Symposium, Chile, 85.41:1-20.

Lazaridou, A. and Psarra, S, 2015, July. 'Experiencing three-dimensional museum environments: An investigation of the Ashmolean Museum and the Museum of Scotland.' In Proceedings of the 10th International Space Syntax Symposium, University College London (pp. 025.1-25).

Lazaridou, A. and Psarra, S., 2017, July. 'Spatial navigation in real and virtual multi-level museums'. In *Proceedings of the 11th International Space Syntax Symposium,* Instituto Superior Tecnico, Lisbon (pp. 14-1).

Peponis, J., and Hedin, J., 1982. 'The spatial layout of theories in the Natural History Museum'. *9H*, *3*, pp.21-25.

Psarra, S., 2009. *Architecture and Narrative: The formation of space and cultural meaning*. London: Routledge.

Psarra, S., Wineman, J., Xu, Y. and Kaynar, İ., 2007. 'Tracing the Modern - Architecture and Narrative Content at the Museum of Modern Art (MoMA) and its latest Expansion', *Proceedings of the International Space Syntax Symposium VI*, Istanbul Technical University, Istanbul, Turkey. 70.1-16 .

Psarra, S. and Grajewski, T., 2000. 'Architecture, narrative and promenade in Benson+ Forsyth's Museum of Scotland.' *ARQ: Architectural Research Quarterly*, *4*(2), pp.123-136.

Sailer, K., Penn, A. (2009), 'Spatiality and Transpatiality in Work Place Environments', 7th ISS Symposium, Stockholm, 095:1-11.

Seo, Y. and Ahn, J., 2010, September. 'On Reducing the Impact of Exceptional Conditions on Museum Sightseeing Crowdedness Control Mechanisms.' In *International Conference on Security-Enriched Urban Computing and Smart Grid,* Springer, Berlin, Heidelberg (pp. 206-212).

Serota, N., 1998. 'The New Tate Gallery of Modern Art.' *Casabella*, *661*, p.14.

Stavroulaki, G. and Peponis, J., 2003, June. 'The spatial construction of seeing at Castelvecchio'. In *Proceedings of the 4th International Space Syntax Symposium,* University College London, London (pp. 66-1).

Tsiropoulou, E.E., Thanou, A. and Papavassiliou, S., 2017. 'Quality of experience-based museum touring: A human in the loop approach.' *Social Network Analysis and Mining*, *7*(1), p.33.

Tzortzi, K., 2003, June. 'An approach of the microstructure of the gallery space: The case of the Sainsbury Wing.' In *Proceedings of the 4th International Space Syntax Symposium,* University College London, London (pp. 67-1).

Tzortzi, K., 2007, June. 'Museum building design and exhibition layout.' In *Proceedings of the 6th International Space Syntax Symposium,* Istanbul Technical University, Istanbul (Vol. 1215, p. 072).

Tzortzi, K., 2011. 'Space: interconnecting museology and architecture.' *The Journal of Space Syntax*, *2*(1), pp.26-53.

Wineman, J.D. and Peponis, J., 2010. 'Constructing spatial meaning: Spatial affordances in museum design'. *Environment and Behavior*, *42*(1), pp.86-109.

Yoshimura, Y., Sobolevsky, S., Ratti, C., Girardin, F., Carrascal, J.P., Blat, J. and Sinatra, R., 2014. An analysis of visitors' behavior in the Louvre Museum: A study using Bluetooth data'. *Environment and Planning B: Planning and Design*, *41*(6), pp.1113-1131.