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The Interplay between Spatial Layout and Visitor Paths in Modern Museum Architecture

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Abstract: This study investigates the transformative potential of contemporary museum architecture, emphasizing the intricate relationship between management requirements and spatial design. Contemporary museum practice must adapt to diverse visitor preferences and secure operational funding beyond public sources by increasing ticket sales through personalized visitor pathways. This necessity has led to a growing trend of reconfiguring permanent collections via temporary exhibitions to enhance performance and revenue. The study aims to demonstrate the strategic utilization of material and technical opportunities within museum structures, underscoring the critical role of spatial organization in optimizing functional arrangements and enriching the visitor experience. Methodologies include integrating museum management needs into architectural design and employing revised spatial configurations to improve accessibility and connectivity. A case study of the City Museum of Belgrade's central building illustrates these methodologies' application, enhancing direct access to galleries and expanding potential walking routes. Detailed analysis reveals that redesigned museum layouts can significantly boost efficiency, performance, and visitor satisfaction, thereby supporting the overall sustainability of cultural institutions. This approach enables traditionally resistant public museums to adapt to modern challenges by developing services and programs that attract diverse audiences and enhance visitor experiences, ultimately contributing to their economic, environmental, social, and cultural sustainability.

Keywords: museum architecture; architectural heritage; design methodology; museum management; spatial layout

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1. Introduction

Public museums have long prioritized non-economic objectives and upheld their traditional roles and practices, often resisting calls for reform [1]. However, with the advent of modern leisure and entertainment options, they have found themselves engaged in a competition for visitors [2,3] while contending for public funds alongside other public institutions [4,5]. In other words, two major challenges that public museums worldwide have recently begun facing include shifts in the preferences of potential visitors and the imperative to navigate reductions in public financing. Approaches to address these challenges primarily center on developing services and programs to appeal to diverse audiences and improving the visiting experience to increase visitor numbers and generate new income from admission to supplement the budget funding [6–8]. Public museums have, therefore, begun transitioning toward a more business-like model for their operation and revenue streams to improve efficiency and performance [1,9], which are crucial aspects of their economic sustainability [10]. According to many authors, achieving economic sustainability represents a prerequisite for ensuring the other three pillars of museums' sustainability—environmental, social, and cultural [11–13]. Museums' efficiency and performance have garnered significant academic attention, with numerous researchers assessing them based on different methodologies and through case studies worldwide [7,14–18].

The selection of strategies aimed at enhancing efficiency and performance primarily relies on specific opportunities available to each museum, classified into five groups by Půček et al. [19] (p. 70)—financial, organizational, legal, material, and technical. While all of them deal with savings, rationalization, and management improvements, financial, organizational, and legal opportunities may or may not be dependent on the architectural aspects of a museum building or have an impact on visitors, whereas material and technical opportunities necessitate a spatial dimension and can directly influence visitors' experience. This is particularly significant as attendance is considered a key performance parameter, with admission revenue being regarded as the primary source of earned income [20]. In brief, material opportunities involve the management of collections, exhibitions, and events, while technical opportunities relate to the more efficient use of museum assets, including the building's space, infrastructure, equipment, and land [19].

In the current era of ephemerality and transience, where there is a preference for the temporary over the permanent, museums are increasingly prioritizing the development of temporary exhibitions [21], which may be interpreted as their material opportunity. These exhibitions serve as potent strategic tools for enhancing performance. They not only instantly trigger visits, providing additional revenues, but also act as effective marketing devices, increasing media attention, attracting sponsors, and enhancing the museum's prestige and public image, potentially leading to long-term financial benefits [21–23]. Recently, there has been a growing trend to reconfigure permanent collections and present them through temporary exhibitions [24]. However, organizing these events necessitates adequate space and has its requirements, such as facilitating independent access from permanent exhibitions, thereby directly affecting the museum's spatial layout.

Over the past two decades, much of the literature on museum architecture has centered on analyzing internal spatial organization to optimize the arrangement of functions, enhance the utilization of museum space, maximize spatial efficiency, and improve the visiting experience [24–28] or to leverage museums' technical opportunities. As Ambrose and Paine argue [29] (p. 206), museums should be managed in the knowledge that their form and spatial organization are likely to be redesigned over time "as values and attitudes, policies and professional practices change and evolve" and many of them have undergone technical alterations and adaptations to address various challenges and needs.

According to Tzortzi [30], the functionality of a museum's spatial layout extends beyond the properties of individual spaces, being contingent upon the intricate relations between them. These relations ultimately shape the museum's overall configuration, comprising a system of spatial connections that impact how visitors navigate and explore the exhibitions, thus defining the visiting experience [25,31–33]. This means that two identical layouts may differ in configuration solely based on the arrangement of doors/openings, influencing the visit differently. Investigating the effects of a museum's configuration on visitors' movement patterns and experience is thus rooted in understanding how individual spaces form relationships with each other within a larger system [33].

Choi's discussion on the relationship between museum configuration and patterns of visitors' movement and exploration is highly influential in this field [34]. He identified two distinguishing models according to which museum layout structure visits. The deterministic model dictates viewing sequences and restricts circulation choices, thus forcing or controlling visitors' exploration. In contrast, the probabilistic model permits selection and allows for random movement through space. Choi suggests that the patterns of movement and exploration are integral to the visiting experience and significantly influence the museum's quality, arguing that the architecture and spatial layout thus determine the overall museum experience.

Another influential work comes from Hillier and Tzortzi [25], who introduced the concept of "space types" to identify the museum's configuration and assess its impact on visitors' movement, exploration, and, ultimately, their experience. They proposed categorizing each exhibition space (room) based on its communication with neighboring ones and its position within the layout. According to them, most museum layouts combine "c-type" or "sequence spaces" and "d-type" or "choice spaces". To explain the influence of their arrangement on the visiting experience, the authors examined two extreme possibilities. In one extreme, a layout comprises solely c-spaces, where every visitor follows the same sequence of spaces in the same order ("single ring of spaces"), akin to Choi's deterministic model. Such a configuration is effective when accompanied by an underlying narrative guiding the visit (as in the case of chronological display of an artist's work); however, without a necessary narrative, an overly sequenced layout imposes unnecessary limitations. On the other extreme, every space is a d-space connected to all its neighbors, offering visitors multiple circulation alternatives at every point with no constraints ("grid of spaces"), like the probabilistic model. While this configuration ensures each visit is unique, navigating such a layout may prove challenging. Hillier and Tzortzi note that achieving a balance between c- and d-spaces involves crafting a layout characterized by localized and interconnected sequences, along with an appropriate degree of structured choice. This allows visitors to construct their patterns of exploration and maintain a certain degree of intellectual control over the visit. In his recent work, Tzortzi suggests that the traditional museum layout uses space instrumentally to create organized sequence/s ("ring/s of spaces"), facilitate visitor navigation and viewing, and relate the sequence to a particular narrative [35] (p. 66). In contrast, there are examples of redesigned museums with layouts that use space more expressively and purposely engage different patterns of movement and viewing, "ranging from the sequential and structured to the exploratory and random", to spatially construct meaning and create distinctive experiences (p. 76). The spatial layout can thus impact the intelligibility of a museum, both as a navigation tool and a framing environment, implying that a museum's architecture and configuration should provide an "intelligible framework" for visitors to select what they want to see, process their experience, and create their own meanings [30] (p. 37.4). However, Hanna argues that where there are multiple choices to be made, such as in large museums, intelligibility does matter, while where the path is predetermined, it may not: "in these spaces, we are free to ignore the effort of choosing the next gallery and may trust in the space in a way we would not in an unfamiliar forest" [31] (p. 97). According to Bal [36] (p. 4), "walking through a museum is like reading a book", with two overlapping narratives—one textual, providing information on the exhibited, and the other spatial, which arises from the "sequential nature of the visit", that is, the way the walking tour is conceptualized. Therefore, as Tzortzi argues, "the design of space is the common point of reference for architecture and museology" [24] (p. 1).

In instances where an existing building is being repurposed into a museum, and there are constraints on altering the layout (e.g., due to heritage protection), there is a need for a methodology to calculate all possible visitor paths with minimal (or no) layout modifications. By systematically approaching the challenge of calculating visitor paths with layout modifications, museums can effectively repurpose existing buildings while respecting heritage constraints and enhancing visitor experience. This methodology might ensure that the museum layout provides optimized visitor flow and engagement within the historical context of the building. In the context of contemporary museum management trends, this paper examines the transformative role of museum architecture, with a specific emphasis on the intricate relationship between management requirements and spatial layout. It investigates how public museums, traditionally resistant to change, might adapt to modern challenges by developing services and programs aimed at attracting diverse audiences and enriching visitor experiences.

The study aims to evaluate the use of material and technical resources within museum buildings, highlighting the significance of spatial organization in optimizing functional arrangements and enhancing the visitor experience. Key methodologies explored include the integration of museum management requirements into architectural design processes and the implementation of revised spatial configurations to improve accessibility and connectivity. The primary objective of this research was to comprehensively map all potential visitor pathways within the existing building of the City Museum of Belgrade. This investigation is illustrated through a detailed case study of its central building, demonstrating the practical application of proposed methodologies to maximize direct access to gallery spaces and increase the number of potential visitor routes. Through rigorous analysis, the research underscores that redesigned museum layouts can significantly improve operational efficiency, performance metrics, and visitor satisfaction, thereby enhancing the overall sustainability of cultural institutions.

2. Objectives and Museum Management Requirements

The subject of this research is the historic building of the New Military Academy, which is currently being transformed into the central edifice of the City Museum of Belgrade. The architectural project for this reconstruction won first prize in a competition held in 2016. The winning design was submitted by the BIRO.VIA studio (authors: J. Ivanović Vojvodić, G. Vojvodić, and J. Grujevska; collaborators: D. Radišić, M. Obradović, M. Plamenac, and S. Jeličić; and consultants: D. Jovović Prodanović, J. Jonaš, and Z. Miletić) [37]. The final blueprints for the project, titled "Reconstruction and Extension of the Building for Conversion into the Museum of the City of Belgrade", were completed in 2021 [38] (Figure 1).

Figure 1. *Cont.*

Figure 1. Visualization of the building's exterior. From the upper: street view, main entrance (hereinafter UL1), courtyard view, and interior view with main staircase. Source: https://birovia.rs/en/projects/rekonstrukcija-i-dogradnja-objekta-za-prenamenu-muzej-grada-beograda/ (accessed on 20 May 2024).

The building was constructed based on the design by Dimitrije T. Leko, embodying the spirit of Neo-Renaissance architecture. The first section was erected in 1899, with an additional section facing Nemanjina Street added after World War I. The building represents one of the most notable achievements of its architect. At the time of construction, a military academy already existed nearby; hence, the building was named the New Military Academy. Throughout its operational period, it housed the military forces of the Kingdom of Serbia (until World War I) and the Kingdom of Yugoslavia (during the inter-war period).

Records regarding any damage the building might have suffered during World War I are unavailable. However, it sustained significant damage during World War II bombings. Over the years, various adaptations and repairs were conducted, with documentation preserved in the Army Archive and later handed over to the city administration. The exterior appearance remained largely unchanged, except for the creation of a vehicle passage from Birčaninova Street into the courtyard, designed in 1962. Further adaptations of both wings were conducted in 1964, with additional adaptations occurring in the following decades. After 1999, the building was partially vacated. Its current function was determined in early 2007, when the City of Belgrade acquired the building from the Ministry of Defense to accommodate the City Museum of Belgrade, which lacked a permanent exhibition space. The area around Kneza Miloša Street, where this museum is situated, has been designated as a spatial cultural-historical unit, granting the building "under previous protection" status [39].

For the purposes of this research and given that the reconstruction based on the competition-winning entry is currently underway, the reconstructed state of the museum will be regarded as presently existing and immutable.

The primary objective of this research was to identify all potential visitor pathways within the existing building allocated to the City Museum of Belgrade, as guided by the following management requisites:

1. Preservation of heritage and architectural integrity: Due to heritage protection laws and architectural copyrights, the building's layout and facades cannot be altered using permanent elements.
2. Revenue enhancement through diversified pathways: There is a necessity to increase museum revenue derived from ticket sales. The premise is that this can be achieved by expanding the museum's offerings regarding possible visitor pathways, thereby providing a greater variety of time allocations suitable for different visitor types. Additionally, a comprehensive list of potential visitor paths could introduce a new parameter in the creation of narratives for each pathway. Each proposed path should undergo further analysis by museum curators.
3. Prioritization of shorter routes: Considering the points, museum management acknowledges the need to prioritize shorter routes. This is due to the significant time consumption associated with pathways that require visitors to traverse multiple exhibitions to reach one of their interests. Concerning the museum's layout arrangement, three types of walking routes can be identified [25,34,35] (Figure 2):
   - Linear type: Typically found in historic buildings with an enfilade layout arrangement. In this case, the doors leading to each room are aligned along a single axis, restricting movement. Visitors must pass through preceding rooms to access subsequent ones, which limits the number of potential walking routes.
   - Divergent type: Found in both contemporary and historic buildings, especially those with multiple wings. This type allows for more varied routes as visitors can diverge from a central point to explore different parts of the museum.
   - Hall type: Characterized by multiple routes intersecting in a central zone, which is advantageous for organizing autonomous exhibitions with separate tickets.
4. A tool designed to generate all possible visitor pathways could serve as a platform not only for developing new narratives but also for advancing technologies that facilitate navigation throughout the museum building (especially in the sense of ensuring that visitor paths conclude at the starting point).
5. The current number of visitors, approximately 123,000 in 2023 for the indoor exhibitions, is planned to triple in the years following the competition of the building's reconstruction.

In relation to the aforementioned points, it is considered that architectural design methodologies explored in this study might be used to facilitate the repurposing of current museum building spaces and the redesign of their layout. It could potentially optimize visitor circulation patterns, redefine visitor paths, and concurrently enhance ticket sales. This investigation encompasses an evaluation of existing museum layouts, aiming to identify opportunities for spatial reorganization that can streamline visitor pathways and foster greater visitor engagement.

The findings presented are confined to modifications in the museum's layout, aimed at enhancing the accessibility of the rooms (galleries) and diversifying visitor pathways, yet without incorporating any new or altering the existing built elements (Figure 3). Consequently, it is important to stress that none of the existing rooms have been altered in dimension or function, nor have any new staircases been added. The only modification that is proposed involves reclassifying certain staircases from "employee only" to public access.

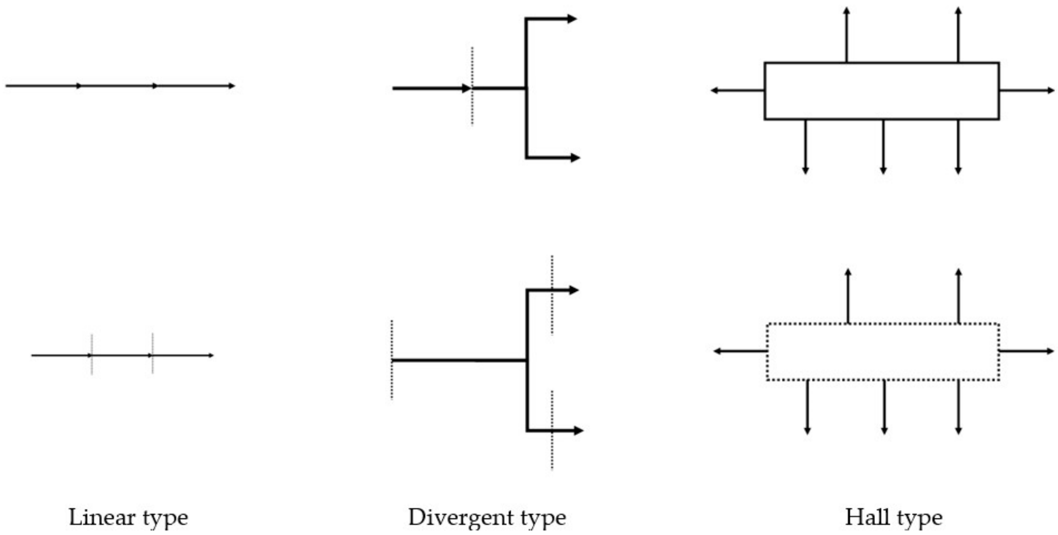

Figure 2. A schematic representation of lines of movement through museum spaces, showcasing a progression from simple linear routes toward more complex ones within divergent or hall types. The dotted line signifies the potential start of a new exhibition with separate tickets. Additionally, the linear type typically represents a visitor path that requires a longer time, whereas the hall type serves as an intersection point for a greater number of shorter routes.

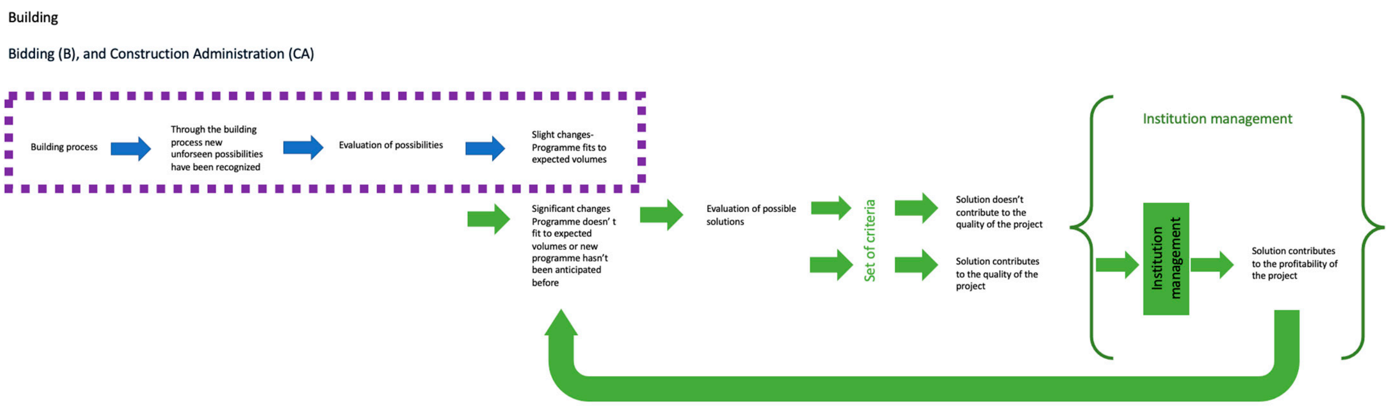

Figure 3. Diagram illustrating the modalities of integrating management requirements during the construction phase of the museum. The dashed line indicates the variation specifically implemented in this research, indicating that no permanent changes to the museum's layout are necessary.

3. Methodology

The design methodology applied in this research strongly relies on Tzortzi's notion of museum space as a shared reference point between architecture and museology [24]. This concept is central to understanding how museum spaces can be designed to enhance the visitor experience. Tzortzi's idea emphasizes that museum spaces are not merely containers for exhibits but are dynamic environments that influence how visitors interact with the displayed objects and with each other.

Another crucial methodological input stems from the sphere of museum management, where maximizing the number of possible walking routes (possible narratives that visitors can follow) correlates with increasing museum ticket sales, thereby enhancing the institution's financial viability and development potential. This approach suggests that by designing spaces that offer multiple paths and narratives, museums can cater to a diverse audience, encouraging repeat visits and longer engagement times. As visitors explore different routes and narratives, they are more likely to have enriching and varied experiences, which in turn supports the museum's goals of education, engagement, and financial sustainability.

Given the aforementioned, the methodology applied in this research can be represented diagrammatically (Figure 4).

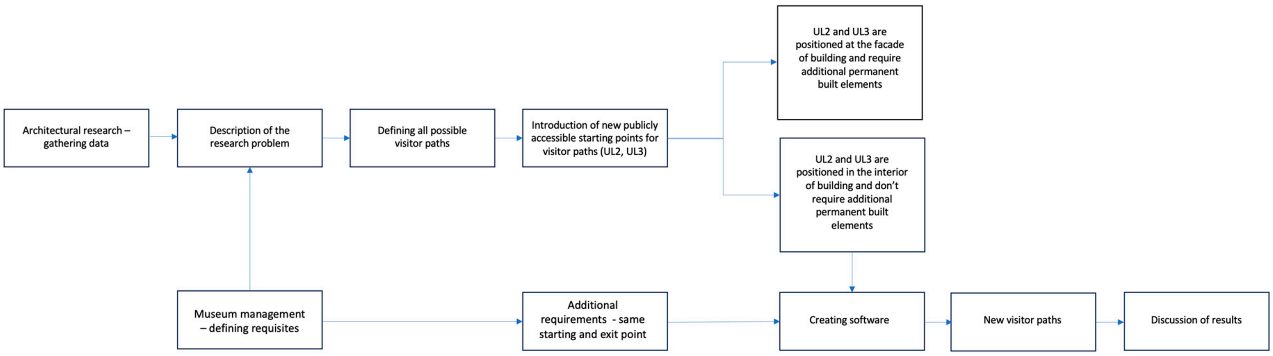

Figure 4. Methodology of the research.

The narrative potential of all possible visitor paths is beyond the scope of this research, as defining it would require incorporating parameters concerning the museum policy and the nature of each exhibition (temporary or permanent). Nevertheless, the methodology presented herein enhances the possibilities even within an enfilade organized layout, where the themes of the exhibition are presented chronologically in space. Additionally, aspects such as natural and artificial lighting, ventilation, and other technological systems essential for museum safety have not been independently addressed because they are integrated into the architectural and related projects accompanying the museum's design and construction. In this particular case, these projects have already received approval from the relevant government institutions.

4. Transformative Capacities of the Museum Layout

The application of the methodology outlined in Section 3 will be demonstrated through the transformation of the layout of the central building of the City Museum of Belgrade. This transformation will be presented with figures and corresponding tables for each floor of the museum building, distinguishing between two states: the "initial state", which represents the conceptual design that won the architectural competition, and the "refitted state", which shows the optimized layout. Bubble diagrams have been used to illustrate the connections.

In analyzing the initial state concerning the management's imperative to optimize the distribution of gallery spaces, the main drawback identified was the way they are connected to the entrances, specifically the lack of direct access to individual galleries. The connections between entrances and gallery spaces, as well as the interconnections between galleries, predominantly belong to a linear type. Two essential criteria for the "refitted" solution are minimizing architectural interventions, including confining them to the building's interior and using non-permanent elements (such as floor signage or ropes), and ensuring all visitors utilize a single main entrance.

To adhere to the established criteria and enhance direct access to individual galleries while maximizing potential walking routes, two auxiliary staircases were activated as "interior entrances/entrance points": UL2 and UL3. They do not have direct connections from the outside of the building and, thus, do not function as traditional entrances. However, they provide access to multiple galleries and effectively connect corridors. It is important to note that UL2 and UL3 are existing staircases, transitioning from "employee only" to "public and employee" access. Additionally, new corridors (C1, C2, C3, and C4) have been introduced, which do not require physical separation by fixed elements like walls; instead, they can be delineated using floor markings or other types of signage systems, such as gallery ropes. This approach ensures no rooms need to change their function. The primary impact involves a reduction in exhibition space due to the incorporation of C1, C2, C3, and C4. However, this reduction can be mitigated through curatorial expertise and the selection of objects for display, leveraging the museum's collection, which encompasses items suitable for non-wall display. All corridors and staircases are treated as extensions of semi-public space within the museum context. UL2, UL3, C1, C2, C3, and C4 have been repurposed and integrated to facilitate access to gallery spaces that are not directly linked to the entrances or staircases in the current state.

Figure 5 and Table 1 depict the connections between the entrances and gallery spaces on the ground floor of the museum. As individual galleries can be accessed from the existing entrance UL1, no interventions were needed except for the existing corridor. In the refitted state, this corridor serves as a link between the main entrance and staircases UL2 and UL3. With the connection between the main entrance UL1 and entrances UL2 and UL3 established, Figure 6 and Table 2 present the refitted layout of the first floor, where corridor C2 has been added. The purpose of this corridor is to enable a connection between staircases UL2 and UL3, thereby extending possible walking routes. Following the same criteria, corridors C2, C3, and C4 were integrated, as illustrated in Figure 7 and Table 3 for the second floor. The subsequent section delves into the newly established connections, comparing the initial and refitted states across various walking route scenarios.

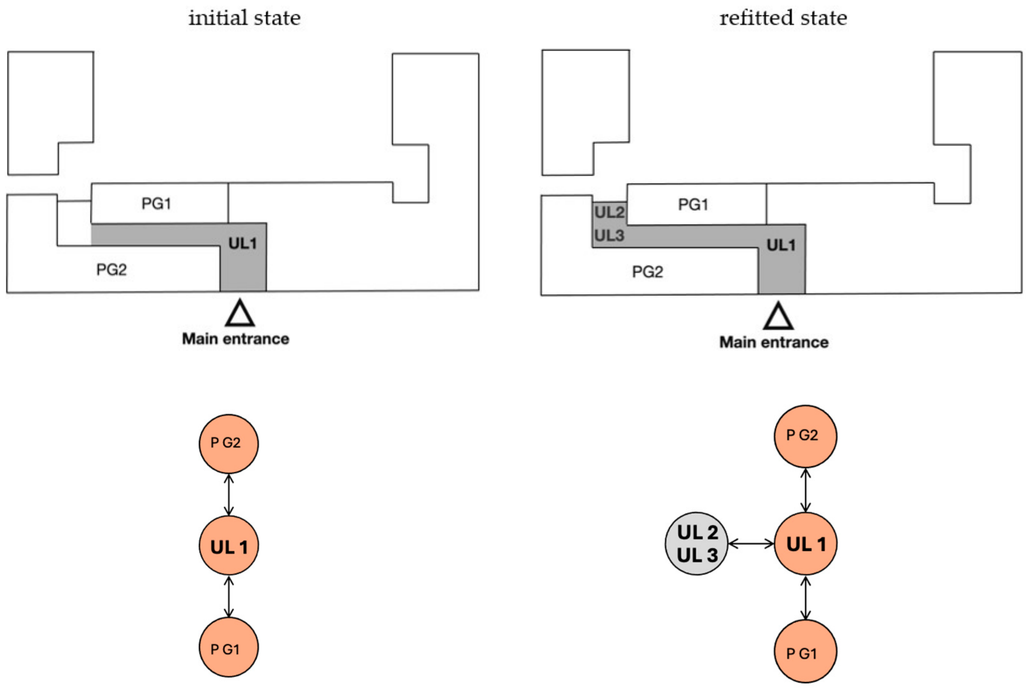

Figure 5. Ground floor plan.

Table 1. Ground floor: the existing entrances and entrances after refitting for galleries PG1 and PG2. In both cases, galleries have direct access from the corridor space. Additionally, a connection for two new entrances is being introduced (further described later in the text).

Direct Entrance from the Corridor		
Gallery	**Initial State**	**Refitted State** [1]
PG1	yes	yes
PG2	yes	yes

[1] Entrance from UL1.

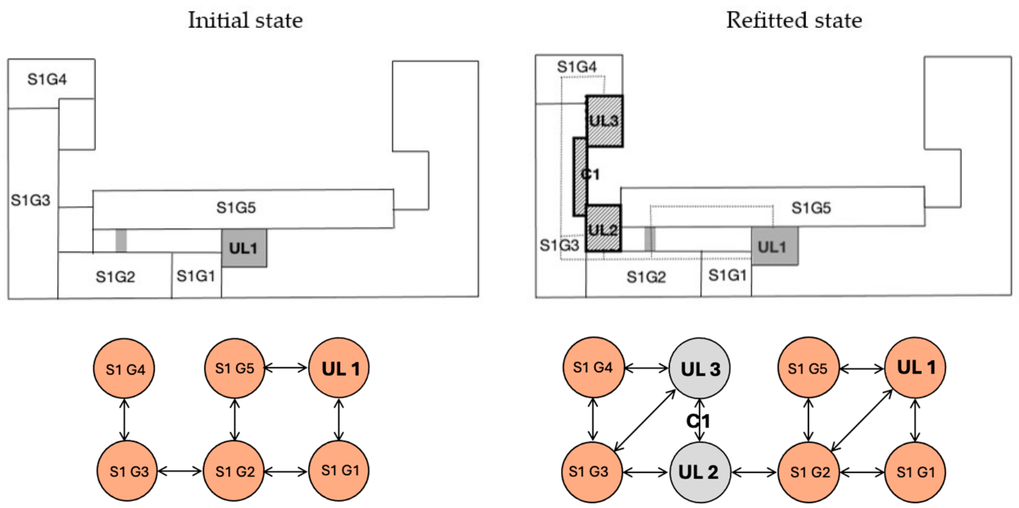

Figure 6. First floor plan.

Table 2. First floor: the existing entrances and entrances after refitting for galleries S1G1, S1G2, S1G3, S1G4, and S1G5, showing that both states maintain direct access from the corridor space. To establish an additional connection between the entrances and ensure continuity of possible walking routes, corridor C1 is introduced between entrances UL2 andUL3.

Direct Entrance from the Corridor		
Gallery	**Initial State**	**Refitted State** [1]
S1G1	Yes	Yes
S1G2	No	Yes
S1G3	No	Yes
S1G4	No	Yes
S1G5	Yes	Yes

[1] Entrance from UL1, UL2, and UL3.

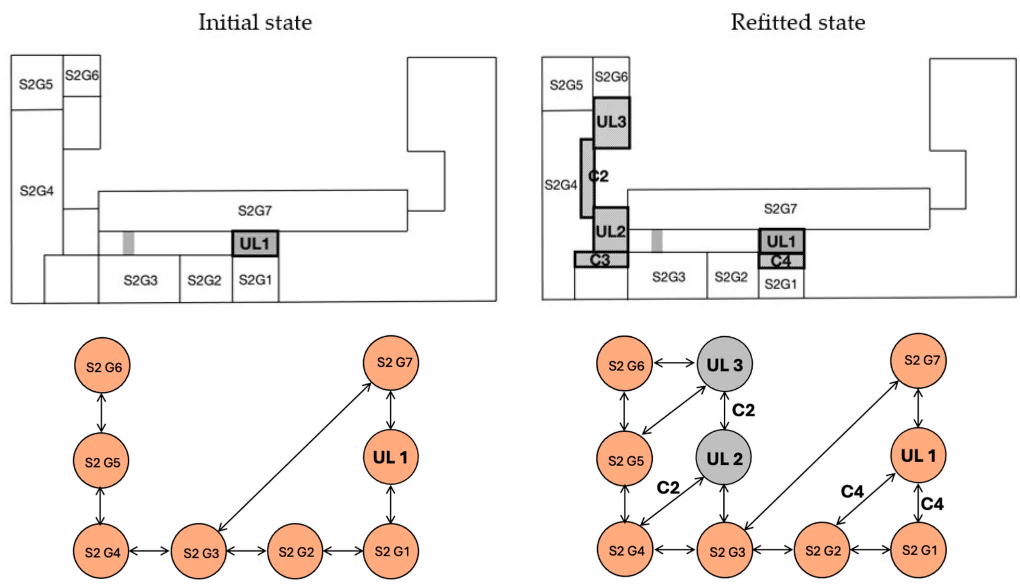

Figure 7. Second floor plan.

Table 3. Second floor: the existing entrances and the entrances after refitting for galleries S2G1, S2G2, S2G3, S2G4, S2G5, S2G6, and S2G7, showing that both states maintain direct access from the corridor space. To establish an additional connection between the entrances and ensure the continuity of possible walking routes, corridors C2 and C3 are introduced between entrances UL2 and UL3. Additionally, to connect S2G2 with Entrance UL1, Corridor C4 is introduced.

Direct Entrance from the Corridor Space		
Gallery	**Initial State**	**Refitted State**
S2G1	Yes	Yes
S2G2	No	Yes
S2G3	No	Yes
S2G4	No	Yes
S2G5	No	Yes
S2G6	No	Yes
S2G7	Yes	Yes

Entrance from UL1, UL2, and UL3.

5. Algorithm Formulation and Resultant Data

For this research, an algorithm has been developed to investigate and compare functional solutions for gallery spaces. This algorithm facilitates the identification of differences between the initial and refitted state of gallery spaces by analyzing various scenarios, including possible walking routes starting from the entrance, the number and connectivity of nodes, and traversal through all rooms and back to the entrance (Table 4).

Table 4. The bidirectional connections between various entrances and galleries in a network. The "galleries entrance" list enumerates all possible nodes. The "connections initial/refitted state" lists map each node (e.g., "UL1", "UL2") to a list of directly connected nodes, indicating bidirectional connections. For example, the node "UL1" is connected to nodes "PG1", "PG2", "S1G1", "S1G5", "S2G1", "S2G2", and "S2G7". This structure defines the network topology, enabling navigation in both directions between connected nodes.

Room Interconnections	
Initial State	**Refitted State**

galleries_entrance= ["PG1", "PG2", "S1G1", "S1G2", "S1G3", "S1G4", "S1G5", "S2G1", "S2G2", "S2G3", "S2G4", "S2G5", "S2G6", "S2G7"]
connections_initial_state = {
"UL1": ["PG1", "PG2", "S1G1", "S1G5", "S2G1", "S2G7"],
"S1G1": ["S1G2"],
"S1G2": ["S1G1", "S1G5"],
"S1G3": ["S1G4"],
"S2G1": ["S2G2"],
"S2G2": ["S2G3"],
"S2G3": ["S2G4", "S2G7"],
"S2G4": ["S2G5"],
"S2G5": ["S2G6"],
}
	galleries_entrance= ["PG1", "PG2", "S1G1", "S1G2", "S1G3", "S1G4", "S1G5", "S2G1", "S2G2", "S2G3", "S2G4", "S2G5", "S2G6", "S2G7"]
	connections_refitted state = {
	"UL1": ["PG1", "PG2", "S1G1", "S1G5", "S2G1", "S2G2", "S2G7"],
	"UL2": ["S1G2", "S1G3", "S2G3", "S2G4"],
	"UL3": ["S1G3", "S1G4", "S2G4", "S2G5", "S2G6"],
	"S1G1": ["S1G2"],
	"S1G2": ["S1G3", "S1G5"],
	"S1G3": ["S1G4"],
	"S2G1": ["S2G2"],
	"S2G2": ["S2G3"],
	"S2G3": ["S2G4", "S2G7"],
	"S2G4": ["S2G5"],
	"S2G5": ["S2G6"],
	}

The algorithm developed for optimizing movement through interconnected galleries generates unique, non-redundant routes from specified entrance points to target galleries. The implementation starts with defining the galleries and their connections in a structured format. This structure is then used to create a network of galleries, ensuring bidirectional connections between them to enable flexible and comprehensive route exploration.

To generate routes, the algorithm employs depth-first search (DFS). The DFS method systematically explores all possible paths, starting from selected entrance galleries and traversing through the connected galleries. During traversal, the algorithm keeps a record of visited galleries in the current route. When the DFS reaches a target gallery, the current path is recorded as a potential route.

To ensure route uniqueness and avoid subsets, the algorithm normalizes each path, ignoring the order of galleries within it. This normalization aids in identifying and discarding routes that are subsets of longer paths. Once all potential routes are generated, the algorithm filters out any routes that are subsets of others, retaining only the longest unique paths.

To better understand the spatial structure and possibilities of walking routes within the museum, three scenarios have been developed and explored. They examine different aspects of navigation and connectivity, offering insights into both the initial and refitted state. By analyzing these scenarios, we aim to demonstrate that the refitted state provides more connections and possible walking routes, highlighting potential improvements in spatial organization.

Scenario 1 explores all possible walking routes starting from the entrance. First, all potential routes to various parts of the museum are identified. Subsequently, using depth-first search (DFS) recursive traversal, they undergo meticulous analysis, providing detailed insights into different routes visitors can take. This analysis offers valuable information about the museum's spatial structure and navigation possibilities (Figure 8).

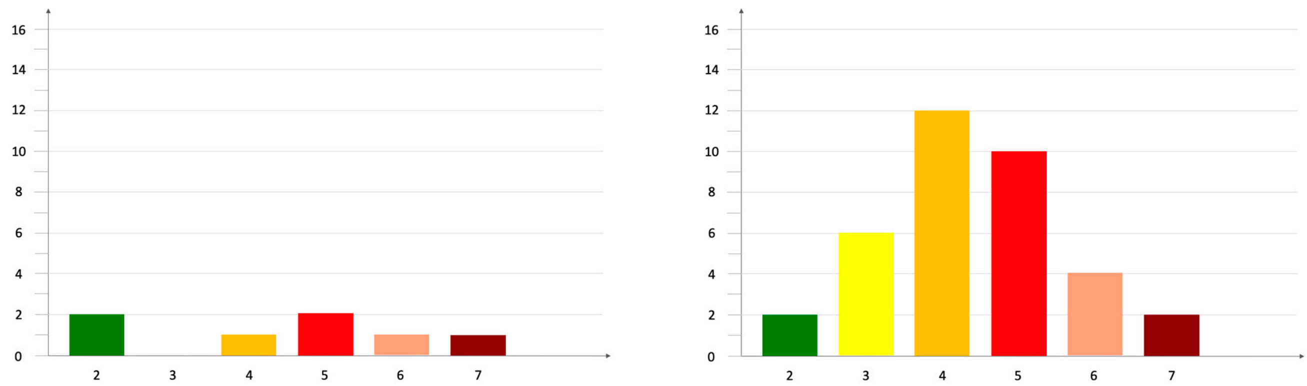

Figure 8. Scenario 1: Analysis of possible routes starting from the entrance using DFS traversal in the initial (**left**) and refitted state (**right**). The diagrams show the relationship between the sum of visited entrances and galleries along a visitor's path (x-axis) and the number of pathways with the same number of visited galleries (y-axis). For instance, the path UL1 > S1G1 > S1G2 > S1G5 would be regarded as a sum of 4 on the x-axis. Green is used to indicate "two-step" visitor paths (sum of 2), yellow denotes "three-step" (sum of 3), and so forth. It is evident that in the refitted state, there is a notable increase in medium-length visitor paths. All data are presented in Appendix A, Table A1.

Scenario 2 focuses on the number and connectivity of nodes (galleries) within the initial and refitted state. First, the number of nodes is calculated, followed by an analysis of their connectivity. This facilitates a quantitative comparison of the spatial structure between the initial and refitted states, providing insights into the complexity and organization of the space (Figure 9).

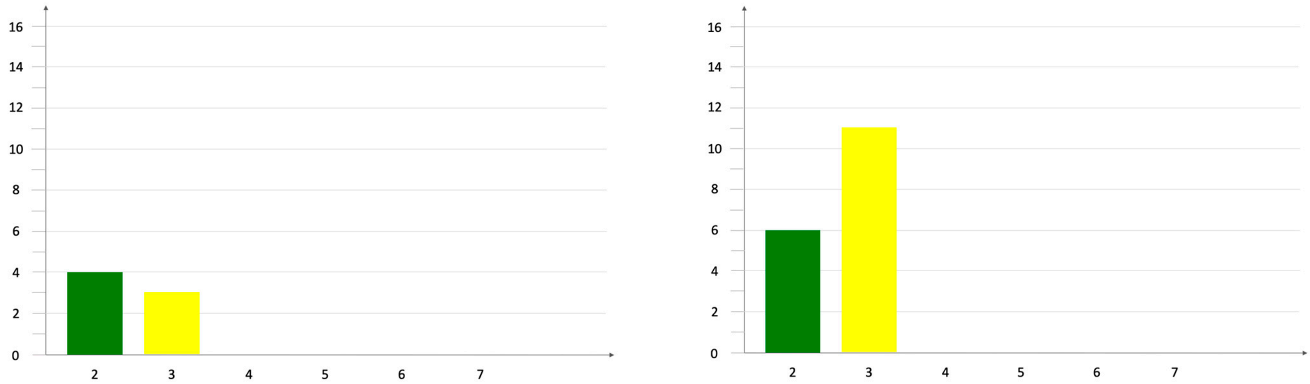

Figure 9. Scenario 2: Quantitative comparison of the number and connectivity of nodes (galleries) between the initial (**left**) and refitted state (**right**). The diagrams illustrate the relationship between the sum of visited entrances and galleries along a visitor's path (x-axis) and the number of pathways with the same number of visited galleries (y-axis). Green is used to indicate "two-step" visitor paths, and yellow denotes "three-step" paths. It is evident that in the refitted state, there is a significant increase in the number of visitor paths. All data are presented in Appendix A, Table A2.

Scenario 3—traversal through all rooms (galleries) and back—explores routes passing through all rooms and returning to the entrance. Through this scenario, the complexity of the space is assessed, and potential challenges in navigating through it are identified (Figure 10).

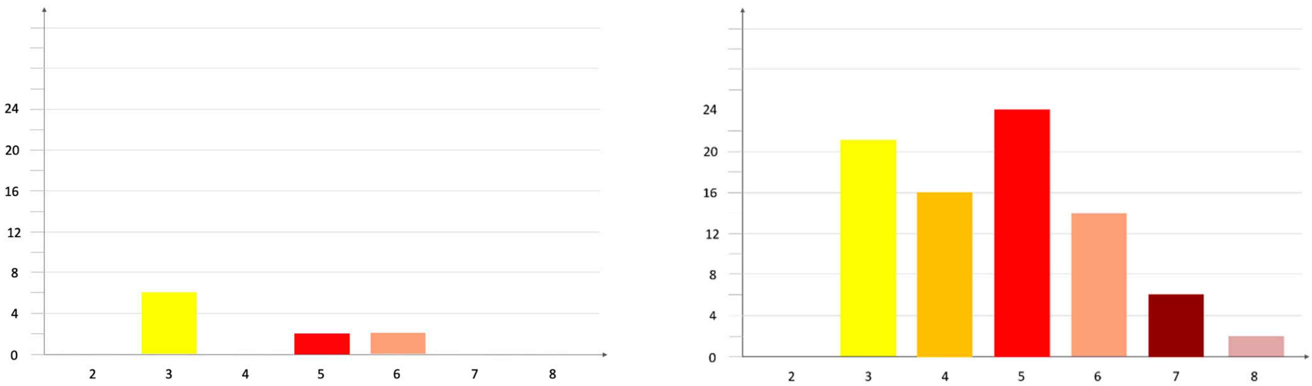

Figure 10. Scenario 3: Detailed exploration of routes that traverse through all rooms and return to the entrance, assessing the complexity of the space and identifying potential navigation challenges in the initial (**left**) and refitted state (**right**). The diagrams illustrate the relationship between the sum of visited entrances and galleries along a visitor path (x-axis) and the number of pathways with the same number of visited galleries (y-axis). Yellow represents "three-step" visitor paths (sum of 3), orange indicates "four-step" (sum of 4), and so forth. It is evident that in the refitted state, there is a significant increase in the number of medium-length visitor paths. All data are presented in Appendix A, Table A3.

Based on the previous analysis of the initial and refitted states of the museum, a trial mobile phone application has been developed to enhance the visitor experience, with its draft interface shown in Figure 11. It leverages insights gained from the detailed spatial analysis to provide visitors with optimized routes tailored to their preferences. For this research, an algorithm has been devised to generate routes based on either purchased tickets or specific galleries a visitor wishes to see. The algorithm prioritizes routes that encompass a higher count of interlinked galleries while excluding those that are subsets of broader routes. Applying this algorithm to museums can provide a deeper understanding of space functionality and enable the identification of potential design improvements.

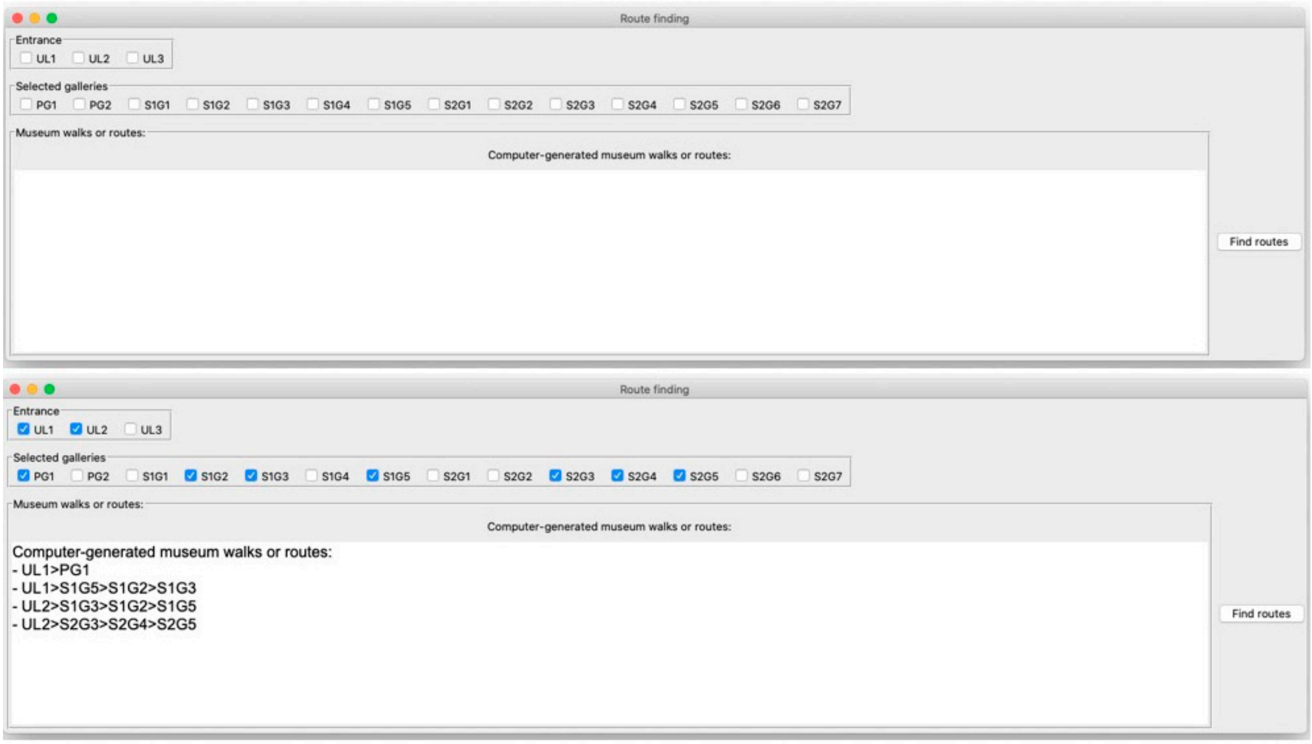

Figure 11. **Top**: Depiction of the initial screen interface of the application. **Bottom**: Illustration showing selected entrances and rooms (galleries) and the corresponding generated routes.

Using the application involves certain steps that define the route and determine the type of ticket:

1. Visitors select the galleries they intend to visit.
2. It is essential to identify the optimal entry point that facilitates the longest route traversing all selected galleries.
3. Optimality is defined as the route that encompasses the greatest number of selected galleries.
4. Participation in gallery visits is contingent upon possessing tickets for the selected galleries.

This trial application serves as a practical implementation of the algorithm, demonstrating its potential to enhance visitor navigation and improve overall satisfaction with the museum. It is available for download on GitHub, allowing the exploration of its features firsthand.

The algorithm's functionalities are integrated into a user-friendly graphical user interface (GUI) developed using Tkinter. The GUI provides an intuitive platform for selecting entrance and target galleries, as well as for displaying the generated routes. It comprises the following components:

1. Entrance selection: Users can select entrance galleries (the first rooms/galleries they wish to visit) from a list of predefined options. Each option is presented with a checkbox, enabling multiple selections.
2. Target selection: Like the entrance selection, users can choose target galleries using checkboxes.
3. Routes display area: This area displays the generated routes. It updates in real time based on user inputs and presents the routes in a formatted text box.
4. Find routes button: A clickable button that initiates the route generation process. Upon clicking, it retrieves the selected entrances and target galleries, executes the DFS-based route generation algorithm, and displays the resulting routes.

To use the application, visitors begin by selecting entrance galleries in the "Entrance Selection" section. Next, they choose the target galleries to be included in the route by checking the boxes in the "Target Selection" section. Finally, they click the "Find Routes" button to generate the optimized routes. The application will process the selections and display the routes in the designated display area. The combination of the network structure, depth-first search-based route generation, and a well-structured graphical user interface ensures that visitors can efficiently generate and visualize optimized routes through the galleries. The algorithm prioritizes the generation of unique, non-redundant routes, offering valuable insights for optimizing movement within the museum. The application is currently in its trial version and serves as a proposal for how such a system could be developed and implemented in a museum setting.

6. Discussion of Results

Based on the data from Tables A1–A3 presented in Appendix A, significant enhancements in connectivity and accessibility were observed in the refitted state compared to the initial state (Table 5). Only Scenario 3, specifically for the two-step path, showed a decrease in the number of pathways.

Table 5. Increase in the number of pathways with the same number of visited galleries (all data presented in Appendix A, Tables A1–A3).

Increase in the Number of Pathways with the Same Number of Visited Galleries [1]							
Scenario	**Two-Step Path**	**Three-Step Path**	**Four-Step Path**	**Five-Step Path**	**Six-Step Path**	**Seven-Step Path**	**Eight-Step Path**
1	0	6	11	8	3	1	0
2	2	8	0	0	0	0	0
3	0	17	16	22	12	6	2

[1] Sum of new paths: 114 (represents an increase of 375% compared to the existing pathways).

In the initial state, the possible walking routes starting from the entrance, UL1, were limited and less interconnected. However, the refitted state, with activated interior entrances (UL2 and UL3), exhibits a considerable improvement. Direct access to all galleries is facilitated from semi-public zones, such as corridors and staircases. This enhanced connectivity enriches the visitor experience by providing diverse routes and alleviating congestion at key junctures.

The refitted state features a higher number of connections between galleries compared to the initial state. By increasing the number of interconnections, the museum's layout becomes more integrated and navigable. This enhancement not only simplifies movement between different sections of the museum but also allows for a more flexible exploration of the galleries. The enhanced connectivity ensures that visitors have more options to traverse the museum, making the overall spatial structure more robust and less prone to bottlenecks.

In the initial state, navigating through all the rooms and returning to the entrance posed significant challenges due to limited connectivity and complex routes. The refitted state addresses these issues by establishing more direct and interconnected routes, enabling visitors to efficiently traverse all rooms and return to the entrance, enhancing. This highlights the enhanced navigability and reduced complexity of the refitted state. As a result, visitors can plan their routes more effectively, optimizing their use of resources such as time and ticket prices.

Overall, the refitted state of the museum's gallery spaces demonstrates clear advantages over the initial state. By enhancing the number of connections, ensuring access to every gallery from each entrance, and offering more potential walking routes, the refitted state achieves a more efficient layout. These improvements not only enhance the visitor experience but also optimize the overall flow and organization of the museum. The refitted state thus effectively addresses the limitations of the initial layout, resulting in a more accessible, interconnected, and user-friendly environment.

However, this research did not consider the parameters related to the curatorial narrative of any specific visitor path. This intentional exclusion is due to the predominance of temporary exhibitions in contemporary museums. As such, the themes of exhibitions in this research have been simplified to abstract labels, providing a foundation for potential narratives to be developed by museum management.

Here, it is important to emphasize that even minimal changes to the geometry of rooms/galleries can impact the properties of the exhibits, such as spatial dimension, observer distance, and relationships to natural light sources like windows. These changes can potentially lead to visitor disorientation if not carefully managed. To prevent such disorientation, designers can employ several strategies:

1. Clear signage and wayfinding: Implementing clear, consistent signage and wayfinding throughout the museum can help visitors navigate the space more easily. This includes directional signs, maps, and visual cues that guide visitors through different areas without confusion. Utilizing smartphone navigation apps can also enhance accessibility.
2. Interactive and informational displays: Incorporating interactive displays and informational panels can engage visitors and provide context, helping them understand the spatial arrangement and the significance of the exhibits. This approach reduces disorientation by keeping visitors informed and engaged with the museum's layout and content.
3. Adaptive lighting solutions: Using adaptive lighting techniques can manage the impact of natural light on exhibits. For instance, automated blinds or UV-protective films on windows can control light exposure, ensuring artworks are protected while maintaining optimal lighting conditions. Strategically placed artificial lighting can further enhance exhibit visibility and overall visual coherence.
4. Spatial markers: Incorporating distinctive spatial markers such as sculptures, large artworks, or unique architectural features can serve as reference points within the museum. They help visitors orient themselves and navigate the space more easily.
5. Feedback and iterative design: Collecting visitor feedback and using it to make iterative improvements to the layout and design can significantly enhance the overall visitor experience. By understanding how visitors interact with the space and identifying areas where they encounter difficulties, designers can make targeted adjustments to improve navigation, reduce disorientation, and ensure a more enjoyable museum visit for all.

By implementing these strategies, designers can effectively create a museum environment that accommodates changes in room geometry while ensuring that visitors remain oriented and engaged throughout their visit.

7. Conclusions

As demonstrated through the City Museum of Belgrade case study, achieving an increased variety of possible museum walking routes necessitates integrating museum management requirements into the design process. The above-explained design stages can be implemented even during on-site phases, meaning they can be applied to existing historic buildings when multiple staircases or other vertical communication elements are present. In the earlier example, two additional staircases negated the need for exterior modifications, which is a crucial consideration given the building's heritage protection status. This approach ensures the preservation of the building's historical and architectural integrity while simultaneously enhancing its functionality. Moreover, the interior modifications discussed can be accomplished without introducing new permanent elements, such as walls, but instead by utilizing directional signage. Directional signage serves not only as a guide but also as an educational tool, providing visitors with contextual information and enhancing their overall experience. This method maintains the spatial and aesthetic integrity of the museum's interiors, which is particularly important in historically significant buildings where alterations can detract from the original design.

Similarly, access to individual exhibitions can be managed through the incorporation of new technologies, thereby reducing the reliance on additional staff. For instance, QR code scanners can be employed. This approach allows visitors to tailor their museum experience according to their preferences, including interests in specific historical periods or artists, available time, and financial constraints. Implementing digital solutions, such as mobile phone applications or interactive kiosks, can further enhance the visitor experience by offering customized tours, multimedia content, and real-time information about exhibits and events. This adaptability is expected to increase visitor numbers, as the museum's offerings can cater to individuals with limited resources, such as a passerby or a business professional on a lunch break. By providing flexible and efficient access to exhibitions, the museum can attract a broader audience, including those who may not have considered visiting due to time constraints or lack of interest in a traditional museum experience. Additionally, the integration of technology can facilitate data collection on visitor preferences and behaviors, enabling the museum to continuously improve and tailor its offers.

The proposed design method and demonstrated possibilities for payout modifications represent a significant enhancement over the traditional enfilade layout, where access to a specific room or exhibition typically requires passing through preceding rooms, thereby necessitating additional time for the journey. The traditional enfilade arrangement often limits the visitor's ability to customize their experience and can be particularly challenging in large or complex museums. On the contrary, the proposed design facilitates a more efficient and customizable visitor experience, allowing for a non-linear exploration of the museum's collections. Furthermore, the proposed design approach aligns with contemporary trends in museum curation and visitor engagement, which emphasize interactivity, personalization, and accessibility. By adopting these strategies, the museum can not only preserve its historical significance but also remain relevant and appealing to modern audiences. The implementation of these design and management strategies represents a forward-thinking approach to museum operations, ensuring that cultural heritage is accessible, engaging, and adaptable to the diverse needs and interests of today's visitors.

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Data Availability Statement: The presented application data are available at: https://github.com/kabinet304/Museum-Route-Finder (also at https://figshare.com/articles/journal_contribution/Museum_Route_Finder/26087923). Diagrams and layout drawings are developed from the documentation available at: https://birovia.rs/en/projects/rekonstrukcija-i-dogradnja-objekta-za-prenamenu-muzej-grada-beograda/ (accessed on 20 May 2024).

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Appendix A

Table A1. Analysis of possible routes starting from the entrance using DFS traversal.

Scenario 1: Using Depth-First Search (DFS), All Possible Walking Routes Starting from the Entrance Are Identified, Providing Insight into User Pathways and Spatial Structure	
Initial State	**Refitted State**
Walking routes from entrance UL1: UL1 > PG1 UL1 > PG2 UL1 > S1G1 > S1G2 > S1G5 UL1 > S1G5 > S1G2 > S1G1 UL1 > S2G1 > S2G2 > S2G3 > S2G4 > S2G5 > S2G6 UL1 > S2G1 > S2G2 > S2G3 > S2G7 UL1 > S2G7 > S2G3 > S2G4 > S2G5 > S2G6 UL1 > S2G7 > S2G3 > S2G2 > S2G1	Walking routes from entrance UL1: UL1 > PG1 UL1 > PG2 UL1 > S1G1 > S1G2 > S1G3 > S1G4 UL1 > S1G1 > S1G2 > S1G5 UL1 > S1G5 > S1G2 > S1G3 > S1G4 UL1 > S1G5 > S1G2 > S1G1 UL1 > S2G1 > S2G2 > S2G3 > S2G4 > S2G5 > S2G6 UL1 > S2G1 > S2G2 > S2G3 > S2G7 UL1 > S2G2 > S2G3 > S2G4 > S2G5 > S2G6 UL1 > S2G2 > S2G3 > S2G7 UL1 > S2G2 > S2G1 UL1 > S2G7 > S2G3 > S2G4 > S2G5 > S2G6 UL1 > S2G7 > S2G3 > S2G2 > S2G1 Walking routes from entrance UL2: UL2 > S1G2 > S1G3 > S1G4 UL2 > S1G2 > S1G5 UL2 > S1G2 > S1G1 UL2 > S1G3 > S1G4 UL2 > S1G3 > S1G2 > S1G5 UL2 > S1G3 > S1G2 > S1G1 UL2 > S2G3 > S2G4 > S2G5 > S2G6 UL2 > S2G3 > S2G7 UL2 > S2G3 > S2G2 > S2G1 UL2 > S2G4 > S2G5 > S2G6 UL2 > S2G4 > S2G3 > S2G7 UL2 > S2G4 > S2G3 > S2G2 > S2G1 Walking routes from entrance UL3: UL3 > S1G3 > S1G4 UL3 > S1G3 > S1G2 > S1G5 UL3 > S1G3 > S1G2 > S1G1 UL3 > S1G4 > S1G3 > S1G2 > S1G5 UL3 > S1G4 > S1G3 > S1G2 > S1G1 UL3 > S2G4 > S2G5 > S2G6 UL3 > S2G4 > S2G3 > S2G7 UL3 > S2G4 > S2G3 > S2G2 > S2G1 UL3 > S2G5 > S2G6 UL3 > S2G5 > S2G4 > S2G3 > S2G7 UL3 > S2G5 > S2G4 > S2G3 > S2G2 > S2G1 UL3 > S2G6 > S2G5 > S2G4 > S2G3 > S2G7 UL3 > S2G6 > S2G5 > S2G4 > S2G3 > S2G2 > S2G1

Table A2. Quantitative comparison of the number and connectivity of nodes (galleries) between the initial and refitted states, highlighting the complexity and organization of the spatial structure.

Scenario 2: The Number of Rooms within Each State Is Calculated, Allowing for a Quantitative Comparison of Spatial Complexity between Current and Newly Designed States	
Initial State	**Refitted State**
UL1<PG1> UL1<PG2> UL1<S1G1>S1G2 UL1<S1G5> UL1<S2G1>S2G2 UL1<S2G1>S2G7 UL1<S2G7>	UL1<PG1> UL1<PG2> UL1<S1G1>S1G2 UL1<S1G5> UL1<S2G1>S2G2 UL1<S2G2>S2G3 UL1<S2G7> UL2<S1G2>S1G3 UL2<S1G2>S1G5 UL2<S1G3>S1G4 UL2<S2G3>S2G4 UL2<S2G4>S2G5 UL3<S1G3>S1G4 UL3<S1G4> UL3<S2G4>S2G5 UL3<S2G5>S2G6 UL3<S2G6>

Table A3. Detailed exploration of routes that traverse through all rooms and return to the entrance, assessing the complexity of the space and identifying potential navigation challenges.

Scenario 3: Routes Passing through All Rooms and Returning to the Entrance Are Explored, Identifying Potential Challenges in Space Navigation and Assessing Its Complexity	
Initial State	**Refitted State**
Walking routes that start and end at the entrances, beginning with entrance UL1: UL1 > PG1 > UL1 UL1 > PG2 > UL1 UL1 > S1G1 > S1G2 > S1G5 > UL1 UL1 > S1G1 > UL1 UL1 > S1G5 > UL1 UL1 > S1G5 > S1G2 > S1G1 > UL1 UL1 > S2G1 > S2G2 > S2G3 > S2G7 > UL1 UL1 > S2G1 > UL1 UL1 > S2G7 > UL1 UL1 > S2G7 > S2G3 > S2G2 > S2G1 > UL1	Walking routes that start and end at the entrances, beginning from entrance UL1: UL1 > PG1 > UL1 UL1 > PG2 > UL1 UL1 > S1G1 > UL1 UL1 > S1G2 > UL1 UL1 > S1G5 > UL1 UL1 > S2G1 > UL1 UL1 > S2G2 > UL1 UL1 > S2G7 > UL1 UL1 > S1G1 > S1G2 > S1G3 > S1G4 > UL3 UL1 > S1G1 > S1G2 > S1G3 > UL2 UL1 > S1G1 > S1G2 > S1G3 > UL3 UL1 > S1G1 > S1G2 > UL2 UL1 > S1G5 > S1G2 > S1G3 > S1G4 > UL3 UL1 > S1G5 > S1G2 > S1G3 > UL2 UL1 > S1G5 > S1G2 > S1G3 > UL3 UL1 > S1G5 > S1G2 > UL2 UL1 > S2G1 > S2G2 > S2G3 > S2G4 > S2G5 > S2G6 > UL3 UL1 > S2G1 > S2G2 > S2G3 > S2G4 > S2G5 > UL3 UL1 > S2G1 > S2G2 > S2G3 > S2G4 > UL2 UL1 > S2G1 > S2G2 > S2G3 > S2G4 > UL3 UL1 > S2G1 > S2G2 > S2G3 > UL2 UL1 > S2G2 > S2G3 > S2G4 > S2G5 > S2G6 > UL3

Table A3. *Cont.*

Scenario 3: Routes Passing through All Rooms and Returning to the Entrance Are Explored, Identifying Potential Challenges in Space Navigation and Assessing Its Complexity	
Initial State	**Refitted State**
	UL1 > S2G2 > S2G3 > S2G4 > S2G5 > UL3 UL1 > S2G2 > S2G3 > S2G4 > UL2 UL1 > S2G2 > S2G3 > S2G4 > UL3 UL1 > S2G2 > S2G3 > UL2 UL1 > S2G7 > S2G3 > S2G4 > S2G5 > S2G6 > UL3 UL1 > S2G7 > S2G3 > S2G4 > S2G5 > UL3 UL1 > S2G7 > S2G3 > S2G4 > UL2 UL1 > S2G7 > S2G3 > S2G4 > UL3 UL1 > S2G7 > S2G3 > UL2 Walking routes that start and end at the entrances, starting from entrance UL2: UL2 > S1G2 > UL2 UL2 > S1G3 > UL2 UL2 > S1G5 > UL2 UL2 > S2G3 > UL2 UL2 > S2G4 > UL2 UL2 > S1G2 > S1G3 > S1G4 > UL3 UL2 > S1G2 > S1G3 > UL3 UL2 > S1G2 > S1G5 > UL1 UL2 > S1G2 > S1G1 > UL1 UL2 > S1G3 > S1G4 > UL3 UL2 > S1G3 > UL3 UL2 > S1G3 > S1G2 > S1G5 > UL1 UL2 > S1G3 > S1G2 > S1G1 > UL1 UL2 > S2G3 > S2G4 > S2G5 > S2G6 > UL3 UL2 > S2G3 > S2G4 > S2G5 > UL3 UL2 > S2G3 > S2G4 > UL3 UL2 > S2G3 > S2G7 > UL1 UL2 > S2G3 > S2G2 > UL1 UL2 > S2G3 > S2G2 > S2G1 > UL1 UL2 > S2G4 > S2G5 > S2G6 > UL3 UL2 > S2G4 > S2G5 > UL3 UL2 > S2G4 > UL3 UL2 > S2G4 > S2G3 > S2G7 > UL1 UL2 > S2G4 > S2G3 > S2G2 > UL1 UL2 > S2G4 > S2G3 > S2G2 > S2G1 > UL1 Walking routes that start and end at the entrances, starting from entrance UL3: UL3 > S1G3 > UL3 UL3 > S1G4 > UL3 UL3 > S2G5 > UL3 UL3 > S2G6 > UL3 UL3 > S1G3 > UL2 UL3 > S1G3 > S1G2 > S1G5 > UL1 UL3 > S1G3 > S1G2 > UL2 UL3 > S1G3 > S1G2 > S1G1 > UL1 UL3 > S1G4 > S1G3 > UL2 UL3 > S1G4 > S1G3 > S1G2 > S1G5 > UL1 UL3 > S1G4 > S1G3 > S1G2 > UL2 UL3 > S1G4 > S1G3 > S1G2 > S1G1 > UL1 UL3 > S2G4 > UL2 UL3 > S2G4 > S2G3 > S2G7 > UL1 UL3 > S2G4 > S2G3 > UL2 UL3 > S2G4 > S2G3 > S2G2 > UL1

Table A3. *Cont.*

Scenario 3: Routes Passing through All Rooms and Returning to the Entrance Are Explored, Identifying Potential Challenges in Space Navigation and Assessing Its Complexity	
Initial State	**Refitted State**
	UL3 > S2G4 > S2G3 > S2G2 > S2G1 > UL1 UL3 > S2G5 > S2G4 > UL2 UL3 > S2G5 > S2G4 > S2G3 > S2G7 > UL1 UL3 > S2G5 > S2G4 > S2G3 > UL2 UL3 > S2G5 > S2G4 > S2G3 > S2G2 > UL1 UL3 > S2G5 > S2G4 > S2G3 > S2G2 > S2G1 > UL1 UL3 > S2G6 > S2G5 > S2G4 > UL2 UL3 > S2G6 > S2G5 > S2G4 > S2G3 > S2G7 > UL1 UL3 > S2G6 > S2G5 > S2G4 > S2G3 > UL2 UL3 > S2G6 > S2G5 > S2G4 > S2G3 > S2G2 > UL1 UL3 > S2G6 > S2G5 > S2G4 > S2G3 > S2G2 > S2G1 > UL1

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