ADAPTIVE EXHIBITION TOPOLOGIES FOR PERSONALIZED VIRTUAL MUSEUMS

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Abstract. The paper addresses the issue of virtual museums’ space personalization. Personalization techniques are poorly integrated in virtual museums implementations and when applied little attention is given in the abilities, requirements and needs of their visitors. In this paper, the concept of adaptive exhibition topologies is introduced. Adaptive exhibition topologies are patterns of space structure that are specifically designed in order to provide unlimited exhibition space for personalized exhibitions based on users’ interests and visiting preferences. Adaptive exhibition topologies focus on the time that visitors are willing to spend for their visit. In contrast to conventional implementations, adaptive exhibition topologies instances are created according to their visitors’ interests and their available time while taking into consideration certain curatorial guidelines. A number of topologies is introduced as well as appropriate metrics for their study and comparison reasons. The effect of different exhibition topologies on users’ navigation and interaction with the exhibits is studied through the conducted usability and evaluation tests.

Keywords: adaptive exhibition topologies, virtual museums, personalization, navigation

1. Introduction
A significant number of works aiming at virtual cultural heritage corresponds to the development of virtual museums and virtual exhibitions represented in 3D virtual environments [1]. Virtual museums and virtual exhibitions have been proposed as effective media for promotion of cultural heritage as they provide solutions for many issues including the lack of available exhibition spaces, their high economic cost and their limited accessibility imposed by geographical constraints [2]. In addition, traditional exhibitions are mostly static and any curatorial interventions are difficult to be performed due to the time, effort and cost needed [3, 4]. Due to their static nature, traditional exhibitions, provide limited personalization abilities which are mostly focused on the exhibition route that is followed and on the narration of the observed artifacts [5-7].

Virtual exhibitions on the other hand, provide theoretically unlimited space, are comparatively less costly, they are world-wide accessible, curatorial changes can be performed
immediately [8], provide ease of access especially for the disabled, all the artifacts can be exhibited and users are able to interact with [2]. In addition, virtual exhibitions can be personalized promoting artifacts that will be of interest to their visitors while their design can be adapted to their needs or further preferences. Personalization provides mitigation of information overload [9] and the ability to control the amount of time dedicating for a information related task [10, 11]. Information overload is considered to be a factor of museum fatigue [12] and museum fatigue is also considered to be increased in time [13].

In this paper, the concept of adaptive exhibition topologies [14] which aim to provide automated construction of virtual exhibitions is presented. Adaptive exhibition topologies provide exhibition spaces that are able to host a variable number of artifacts where the size of the constructed virtual exhibitions and the number of hosted artifacts are determined according to visitors' available time and visiting preferences. The topologies are designed in order to facilitate visitors' navigation and interaction with the exhibited artifacts. Focusing on navigation, special attention is payed on the ability of the presented topologies to provide alternative exhibition routes of reduced distance given the fact that distance in both real and virtual environments is closely linked with visiting time and fatigue [15].

In Section 2, relevant literature and recent related work is reviewed. In Section 3, the proposed adaptive exhibition topologies are presented, their adaptive size properties and their ability to enhance visitors navigation by providing alternative routes of reduced distance are discussed. In Section 4, conclusions on the adaptive exhibition topologies are discussed and guidelines for future work are drawn.

2. Literature Review
Museums’ and exhibitions’ design has been thoroughly studied as it affects visitors behavior and thus is considered an important factor of their success [16]. Psarra [17] study the effect of spatial structure on visitors’ experience while Wineman and Peponis [18] argues that spatial structure shapes the ways in which visitors explore, engage, and understand museums and museum exhibitions. In [19] two, almost opposite, exhibition layouts are studied: (i) the single sequence layout; and (ii) the grid layout. In the single sequence layout, visitors have to traverse a specific sequence of space components. In the grid layout visitors for each position they are placed they are able to choose between the available neighboring space components resulting maximized randomness in the pattern of movement and exploration. In [20] it is stated that museum layouts can be separated in two models: (i) the deterministic; and (ii) the probabilistic, the deterministic model corresponds to the single sequence layout and the grid layout falls into the probabilistic model.

Exhibition design, apart from its spatial characteristics, is closely linked with the arrangement of the exhibited artifacts. Choi [20] notes that the objects on display are usually grouped according to classificatory principles which may be as direct as chronological or geographical origin, or as elaborate as a refined stylistic discrimination and that museum space provides a physical realization of classificatory principles which are supposed to make the collections accessible to understanding.

Regarding virtual museums and virtual exhibitions there are numerous related works but despite their number the literature review reveals that these are not focused on the spatial structure of exhibitions and the user navigation constraints. Kadobayashi et al. [21] propose personalizing museum exhibitions to fit the needs of each visitor by having agents mediate between curators and museum visitors and having the exhibitions be reconstructed for the visitors based on their interests. Wojciechowski et al. [3] present a system that allows museums to build and manage virtual and augmented reality exhibitions based on pre-designed
visualization templates that allows content designers to create virtual exhibitions very efficiently. White et al. [8] present a tool that allows virtual exhibitions to be designed by the use of a presentation manager where the structure of the exhibitions is defined by the structure of exhibition spaces. Bonis et al. [22] presents a content personalization platform for virtual museums which is based on a semantic description of content and on information implicitly collected about the users through their interactions with the museum. Kiourt et al. [23] present a web-based virtual museum framework that provides a complete authoring interface, in which users can create customized virtual exhibitions. Hayashi et al. [24] present a system for automatic generation of personalized virtual museums capable of exhibiting arbitrary planar artifacts, e.g. paintings, which have been specified by the user. The system based on the input automatically creates a 3D environment with flexible walls changing its space in accordance with the specified paintings displayed.

3. Adaptive Exhibition Topologies
In this paper, adaptive exhibition topologies are proposed for the construction of virtual exhibitions’ spaces. The proposed adaptive exhibition topologies provide exhibition designs of variable size in which a certain number of objects are allocated according to curatorial [20] or recommendation instructions based on user’s interests [25]. It is stressed that an exhibition’s size as well as the number of recommended arranged objects can be determined based on user’s available time for the specific visiting session.

Graphs are used to represent the proposed topologies. The topology graphs consist of vertices representing exhibition objects $O$ and edges representing the paths $P$ enabling the transition among them. An object could be a distinct entity of interest or even a room of a museum containing multiple entities of interest belonging to a particular category or context.

The following exhibition topologies are presented in the next paragraphs: (i) sequential; (ii) looped sequential; and (iii) grid.

3.1. Sequential Topology
In sequential topologies the objects are organized in sequence according to specific instructions, i.e., recommendation ranking, chronological arrangement, etc., having only one available route which users are guided to follow, Figure 1. The benefits of the specific layout is that the objects are arranged according to the specified instructions, the visitor needs no further guiding instructions in order to navigate in it and the complete sequential distance can be kept under a certain limit.

![Figure 1. Sequential layout.](image)

3.2. Loopied Sequential Topology
Looped sequential topology is proposed as an advancement of the sequential topology that provides alternative routes of reduced distance. In addition to the sequential topology the sequence forms a loop by adding a path (edge), $p_n = (o_n, o_1)$, connecting the $n_{th}$ object, $o_n$, with the first object of the sequence, $o_1$ Figure 2.
3.3. Grid Topology
In order to further reduce the overall distance of a setting additional paths have to be introduced. The sequential topology is enhanced by separating the sequence in segments of equal distance, the segments are then connected forming a two-dimensional grid, Figure 3. A grid’s size and its capacity is measured in number of objects $O$ and is defined by each dimension’s size given by $O = m \times n$. The objects are allocated in the available positions in each of the $m$ rows and $n$ columns.

![Figure 3. Grid topology instance of dimensional size 3 × 3 containing 9 objects.](image)

3.4. Topology metrics and properties
In order to study the properties of the presented topologies and to be able to compare them a set of metrics related to the traversed distance for a movement from a starting object $o_s$ to a target object $o_t$ is introduced. All the introduced distance metrics are measured in edges (paths) which are considered to be of the same length $p_{1...n}(l) = 1$.

The sequential pair distance,

$$D_S(o_i, o_j)$$

is used to calculate the distance that a visitor has to traverse in order to move from an object $o_i$ to an object $o_j$ given that he/she follows the exhibition sequence.

When visitors visit an exhibition there are cases that they do not follow the recommended exhibition sequence. In such cases there should be alternative exhibition routes of reduced distance. The distances of these alternative routes are given by the minimum pair distance metric,

$$D_M(o_i, o_j)$$

In order to measure the ability of a topology to provide alternative routes of reduced distance, the overall minimum distance, $D_{OM}$, is introduced. The overall minimum distance $D_{OM}$ is calculated as the sum of the distances of the shortest routes connecting every pair of objects.

$$D_{OM} = \sum_{i=1}^{i=n-1} \sum_{j=i+1}^{j=n} D_M(o_i, o_j)$$
3.5. Comparison

The presented topologies are compared for their ability to provide alternative routes of reduced distance. For the comparison the overall minimum distance (Equation 3.4) for topologies instances of varying size is calculated. Figure 4 shows that sequential topology provides the maximum overall distance as it does not provide alternative routes. Looped sequential topology provides reduction of the overall minimum distance (average reduction of 24%) and further reduction is provided by spiral topology (average reduction of 58%).

![Figure 4. Overall minimum distance (Equation 3.4) of (i) a sequential layout; (ii) a looped sequential layout; and (iii) a grid layout. The X axis depicts the size of the layout and the axis Y the overall minimum distance. Sequential layout does not provide alternative routes and does not reduce the overall minimum distance, looped sequential provides average reduction by 24% and grid topology provides average reduction by 58%.](image)

3.6. Navigation Scenarios Evaluation

A testing application (Figure 5) incorporating the described exhibition topologies is developed and used in order to evaluate the efficiency of each exhibition topology in real navigation scenarios. A series of tests including 10 random navigation tasks in: (i) sequential topology; (ii) looped sequential topology; and (iii) grid topology of 25 objects is given to test users. Each random navigation task is tested on all the described exhibition topologies and the time needed in order to complete the task is automatically recorded by the application. For each topology, the average transition time resulting by the random navigation tasks is calculated. The maximum of the average values (the average time of sequential topology) is used as the base value for normalizing the resulted average values for comparison reasons. The results (Figure 6) confirmed that looped sequential topology and grid topology offer alternative routes of reduced distance which can be used by user in real navigation scenarios. More specifically, looped sequential topology provided reduced navigation time by 39% and grid topology provided reduced navigation time by 81%. It is noted that tests resulted greater reduction values than those calculated in Paragraph 3.5. This is attributed to the fact that the tested navigation scenarios include pairs of object of relatively large distance. In case of more navigation scenarios including pairs of objects of shorter distance the average navigation time is expected to be increased accordingly to the results listed in Paragraph 3.5.
Figure 5. Test application. Users are requested to visit specific exhibits assisted by a target indication method. The amount of time needed for their navigation is automatically recorded by the test application.

Figure 6. Visiting scenarios average navigation time comparison. In the conducted tests: (i) looped sequential topology provided reduced navigation time by 39%; and (ii) grid topology provided reduced navigation time by 81%.

4. Conclusions
The present paper’s purpose is to propose adaptive exhibition topologies as a method for automatic construction of personalized virtual museum exhibitions. Adaptive exhibition topologies aim to provide flexible exhibition spaces that enhance visiting experience by focusing on facilitation of visitors navigation. Sequential topology appears to be appropriate solution in cases that visitors follow a sequence route and interaction with exhibits is mostly focused on consecutive exhibits. Looped sequential topology is proposed for cases of sequence routes that for a visitor to return to start point no further distance should be added to the route. Grid topology enhances visiting experience by providing alternative routes of reduced distance in cases...
that visitors navigate through the exhibition without following a strict sequence route. Finally, this work indicates that alternative adaptive exhibition topologies can be used depending on the exhibition purpose or certain curatorial approaches.

5. Bibliography

[1] Komianos, V., Kavvadia, E. and Oikonomou, K. (2014). Efficient and realistic cultural heritage presentation in large scale virtual environments, *Information, Intelligence, Systems and Applications*, IISA 2014, The 5th International Conference on, IEEE, pp. 1–6.
[2] Tsichritzis, D., Gibbs, S. J. et al. (1991). Virtual museums and virtual realities., *ICHIM*, pp. 17–25.
[3] Wojciechowski, R., Walczak, K., White, M. and Cellary, W. (2004). Building virtual and augmented reality museum exhibitions, *Proceedings of the ninth international conference on 3D Web technology*, ACM, pp. 135–144.
[4] Styliani, S., Fotis, L., Kostas, K. and Petros, P. (2009). Virtual museums, a survey and some issues for consideration, *Journal of cultural Heritage* 10(4): 520–528.
[5] Terrenghi, L. and Zimmermann, A. (2004). Tailored audio augmented environments for museums, *Proceedings of the 9th international conference on Intelligent user interfaces*, ACM, pp. 334–336.
[6] Wang, Y., Stash, N., Sambeek, R., Schuurmans, Y., Aroyo, L., Schreiber, G. and Gorgels, P. (2009). Cultivating personalized museum tours online and on-site, *Interdisciplinary science reviews* 34(2-3): 139–153.
[7] Sparacino, F. (2002). The museum wearable: Real-time sensor-driven understanding of visitors’ interests for personalized visually-augmented museum experiences.
[8] White, M., Mourkoussis, N., Darcy, J., Petridis, P., Liarokapis, F., Lister, P., Walczak, K., Wojciechowski, K., Cellary, W., Chmielewski, J. et al. (2004). Arco-an architecture for digitization, management and presentation of virtual exhibitions, *Computer Graphics International*, 2004. Proceedings, IEEE, pp. 622–625.
[9] Bawden, D. and Robinson, L. (2009). The dark side of information: overload, anxiety and other paradoxes and pathologies, *Journal of information science* 35(2): 180–191.
[10] Radev, D. R., Fan, W. and Zhang, Z. (2001). Webinessence: A personalized web-based multi-document summarization and recommendation system, *Ann Arbor* 1001: 48103.
[11] Liang, T.-P., Lai, H.-J. and Ku, Y.-C. (2006). Personalized content recommendation and user satisfaction: Theoretical synthesis and empirical findings, *Journal of Management Information Systems* 23(3): 45–70.
[12] Bitgood, S. (2009). Museum fatigue: A critical review, *Visitor Studies* 12(2): 93–111.
[13] Davey, G. (2005). What is museum fatigue, Visitor Studies Today 8(3): 17–21.
[14] Komianos, V. (2017). Content personalization approaches in cultural heritage (real, virtual and mixed) environments, Doctoral Thesis, Department of Informatics, Ionian University.
[15] Komianos, V. and Oikonomou, K. (2015). Constrained interest-based tour recommendations in large scale cultural heritage virtual environments, Information, Intelligence, Systems and Applications (IIISA), 2015 6th International Conference on, IEEE, pp. 1–6.
[16] Bitgood, S., Patterson, D. and Benefield, A. (1988). Exhibit design and visitor behavior: Empirical relationships, Environment and behavior 20(4): 474–491.
[17] Psarra, S. (2005). Spatial culture, way-finding and the educational message, The Impact of Layout on the Spatial, Social and Educational Experiences of Visitors to Museums and Galleries In: McLeod, S ed. Reshaping Museum Space: Architecture, Design, Exhibitions. London and New York: Routledge pp. 78–94.
[18] Wineman, J. D. and Peponis, J. (2010). Constructing spatial meaning: Spatial affordances in museum design, Environment and Behavior 42(1): 86–109.
[19] Tzortzi, K. (2007). Museum building design and exhibition layout, Proceedings of the 6th International Space Syntax Symposium, Istanbul, Turkey, Vol. 1215, p. 072.
[20] Choi, Y. K. (1999). The morphology of exploration and encounter in museum layouts, Environment and Planning B: Planning and Design 26(2): 241–250.
[21] Kadobayashi, R., Nishimoto, K., Sumi, Y. and Mase, K. (1998). Personalizing museum exhibition by mediating agents, Tasks and methods in applied artificial intelligence pp. 648–657.
[22] Bonis, B., Stamos, J., Vosinakis, S., Andreou, I. and Panayiotopoulos, T. (2009). A platform for virtual museums with personalized content, Multimedia tools and applications 42(2): 139–159.
[23] Kiourt, C., Koutsoudis, A. and Pavlidis, G. (2016). Dynamus: a fully dynamic 3d virtual museum framework, Journal of Cultural Heritage 22: 984–991.
[24] Hayashi, M., Bachelder, S. and Nakajima, M. (2016). Automatic generation of personal virtual museum, Cyberworlds (CW), 2016 International Conference on, IEEE, pp. 219–222.
[25] Komianos, V., Kavvadia, E. and Oikonomou, K. (2015). Cultural heritage recommendations and user navigation in large scale virtual environments, International Journal of Computational Intelligence Studies 4(2): 151–172.