Layouts of 3D Data Visualizations Small Multiples around Users in Immersive Environments

Parisa Daeijavad*
University of Calgary

Frank Maurer†
University of Calgary

ABSTRACT

Immersive 3D data visualizations have been used in many application areas recently. The importance of having multiple visualization in an immersive environment around the user, attract researchers attention to this question of how to layout different 3D data visualizations in Extended Reality (XR) environments as these visualizations may have natural connections and need to be organized in reasonable layouts around the user in a 3D space. In this paper, we describe a taxonomy for a design space of small multiples' layouts for immersive environments. We argue that these layouts are applicable across different interaction techniques, tasks, data visualization techniques. Our study demonstrates that there are many possible layouts that have not been used yet. These need to be investigated and evaluated.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction techniques; —Interaction paradigms—Mixed / augmented reality; —Virtual reality

1 INTRODUCTION

The technological developments in immersive technology over the past several years have led to the rapid change in Extended Reality (XR) (including VR, AR, and MR), from concept through to commercial possibilities [20]. Currently, flat displays are used mostly for data visualisation. This brings a problem for data that is inherently 3D, because rendering 3D data visualizations on screens suffers from problems with occlusion, perspective distortion, and other similar problems, as well as a general loss of information [13]. But as field of view, and resolution of XR headset devices improves, traditional screens might be inexpensively replaced by wearable headsets that provide immersive representation of such 3D data. There are many visualization techniques for 3D data in immersive environments found in the literature like Munzner's category [16] that includes node-link graph (networks and tree visualizations), scatterplots (multiple data entries, represented as points in 2D/3D coordinate systems), parallel coordinate plots (PCPs: multiple data entries, represented as lines between arranged axes), glyphs, icons and symbols (visual data metaphors that often encode more than one dimension), geographic (real-world geometry representations), volume (3D object visualizations), flow (scalar-, vector-, and tensor-field visualizations), height map visualizations, and Kohonen map representations [11]. These visualizations can be abstract or non-abstract data visualizations. Visualizations of abstract data show data without a natural physical or spatial representation in immersive 3D environments like 3D scatterplots or 3D parallel coordinates [11]. Non-abstract data has inherent spatial properties like CAD drawings or CT/MRI data.

Immersive technologies offers opportunities for the enhancement of the interaction methods, techniques, and approaches provided by 2D displays [20]. XR provides new opportunities via it's various interface components, namely devices, techniques and metaphors, and a broader range of input and output modalities for interaction including tangible devices, aural cues (i.e. speech and para-linguistics), visual cues (i.e. gaze and gesture) and environmental information (i.e. object manipulation, writing and drawing) [3]. Interaction in 3D immersive environments is still complicated and challenging because of a combination of novel, multimodal input and output technologies and demanding complex use cases. Therefore, investigating interaction techniques is important to make sense of and communicate through data [1].

One of the information visualization method is called 'Small Multiple' that is defined as a set of juxtaposed data representations that together support understanding of multivariate information [15]. Small multiples can be represented in a tiled display to provide an overview of the data and to improve user performance for tasks like comparison, search and analysis [13]. Small multiples visualizations are ubiquitous in many contexts such as road traffic data [17], scatterplot matrices [19], medical images [7, 10], and more. Research on 3D data visualization small multiples in immersive environments, has discussed how users utilize space and position as methods to organize and structure different visualizations around themselves in such spaces [8–10, 13, 21]. However, among those that investigated the layout of 3D data visualizations around users in immersive space, only one study proposed a design space for small multiples layouts [13] and work does not consider how interaction techniques will impact proposed design space.

The design space proposed by [13] for immersive data visualisations identified 4 design dimensions. In this paper, we extend this design space by adding the interaction dimension as well as height and detail level dimensions as these three dimensions were not explicitly part of the proposed design space. We then argue that there are layouts that can be derived from the developed design space that to the best of out knowledge, no user study has been conducted to evaluate them for specific visualization techniques, tasks, applications and interaction techniques. Research mostly focus on elicitation studies and a small number of well-known layouts. We postulate that an empirical basis for making immersive layout decisions is mostly lacking.

2 RELATED WORK

Immersive small multiples are a visualization technique for representing and comparing data. Bertin [4] in 1967 introduced small multiples as a data analysis technique that provides users with the ability to sort the collections of related views, but Tufte [22] in 1983 popularized this method and is often credited with the term.

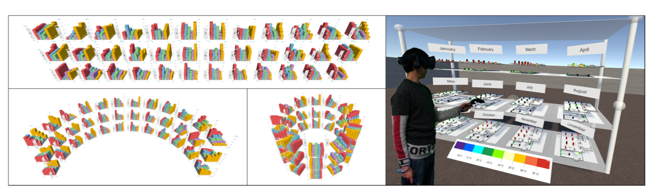

Figure 1: Three different layouts (left); Small multiples in VR using a "shelves" metaphor (right) [13].

*e-mail: parisa.daeijavad@ucalgary.ca
†e-mail: frank.maurer@ucalgary.ca

Small multiples have been used in many real-world use cases of data with a realistic 3D embedding, which is challenging to show on flat screens [13]. Liu et al. [13] use a ”shelves” metaphor seen in Figure 1 for layout of small multiples and consider a design space across a number of layout dimensions. For maps visualization, Satriadi et al. [18] observe the layouts produced by users performing map exploration search, comparison and route-planning tasks. Figure 2 shows some of these used layouts.

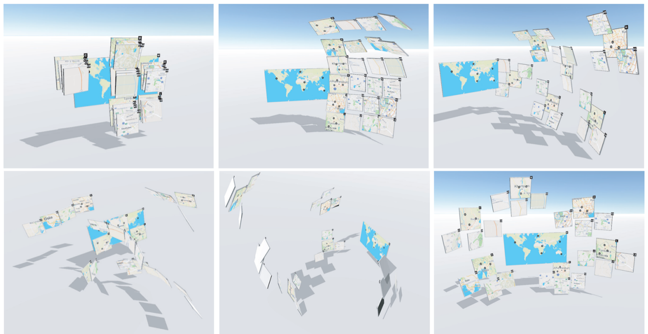

Figure 2: Examples of elicited layouts from users: (A) unidentified, (B) spherical, (C, E, F) spherical cap, and (D) planar [18].

In FiberClay, Hurter et al. [9] visualise small multiples on the ground as in Figure 3, with the focus presented directly in front. Luo et al. [14] investigate the effect of office environments and work styles during a document classification task using AR with regard to content placement, and layout strategies, as Figure 4 depicts them.

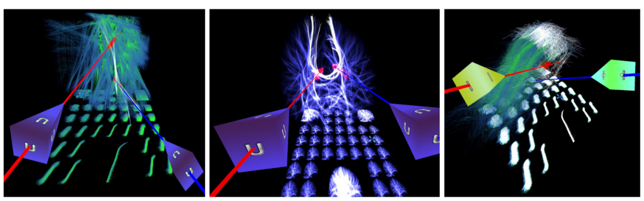

Figure 3: Positioning alternative views on the ground, allow the user to ignore them while interacting with the primary view [9].

In other work, Vohl et al. [23] use a circular layout to visualise small multiples as in Figure 5, right. In Virtual Shelves Li et al. [12] distributes app shortcuts in an invisible hemisphere as can be seen in Figure 5, left.

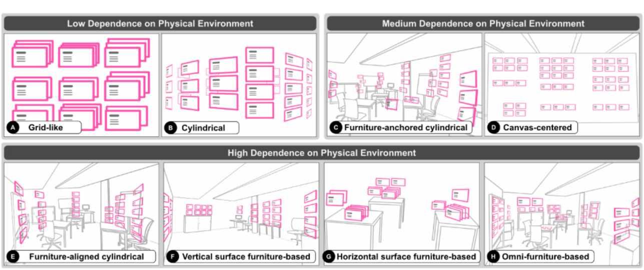

Figure 4: Different layouts, grouped according to the degree of dependence on the physical environment; low (A, B), medium (C, D), and high (E, F, G, H) [14]

From this review, we can note that previous research for small multiples in 3D space, primarily focused on specific layout possibilities such as spherical and semi-spherical layouts and no work has been done to show other possible layouts in the design space and no user study has been done to evaluate the benefits and limitations of these layouts for different tasks and different data visualization techniques. In our work we propose our developed design space for the such layouts and argue that there are unexplored useful layouts for multiple visualization in an immersive space around a user.

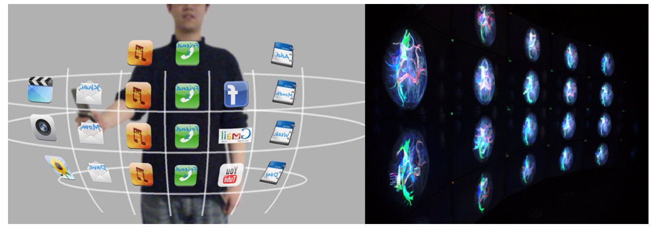

Figure 5: The layout of the Virtual Shelves (left), A subset of the Monash CAVE2 data-sets in semi-spherical layout(right)

3 A Design Space for Immersive Small Multiples

As mentioned in section 1, a design space for small multiples layouts have been proposed in 3D space with 4 design aspects of Dimension, Curvature, Aspect ratio, and Orientation [13]. As small multiples are intractable, users need to reconfigure the small multiples layout by manipulating different dimensions of the layout form. In addition to chancing these 4 dimensions, manipulating the layout includes adjusting the vertical and horizontal space between rows and columns respectively. Therefore, we added Height and Detail level to the design space. Many possible layouts of small multiples for 3D data in immersive environments can be described using these six dimensions as can be seen in Figures 6, and 7. To the best of our knowledge, there is no existing work to explore all possible layouts in such design space. Moreover, we argue that the design space for immersive small multiples has another dimension which is interaction technique, because it can affect the way we lay out 3D data visualizations around the user in immersive environments. Therefore, in the following section, we show all possible layouts in such design space as well as the taxonomy of a design space with seven dimensions, elaborating more on the interaction aspect.

Dimension refers to the dimensionality of the grid of small multiples. 1D layout is a single row layout, 2D is the traditional grid/flat layout, and 3D layout is adding a depth dimension to the grid [13].

Curvature place visualization multiples around the user in a curve shape, reducing the need for walking by putting visualizations within a user’s arms’ reach [13].

Curving 1D layout can be horizontal or vertical and can be in a semi or full circular shape around the user. Figure 6 shows all of these layouts, with two different orientations. 2D grid/flat layout also can be represented vertically or horizontally in front of the user as seen in Figure 7 left, and can be in circular, semi-circular, cylindrical or semi-cylindrical shape as Figure 7 depicts all of these possible ways to curve 2D layouts. Similarly, in order to curve 3D layouts, both circular and cylindrical shapes can be used in different orientations in front of the user.

Aspect ratio relates the number of multiples in each orthogonal dimension. For example, a 2D array of 12 multiples can be arranged in ratios: 4×3, 3×4, 2×6, and 6×2 [13].

Orientation refers to the relative orientations of the individual 3D data visualisations which can either align to the same forward-facing direction or facing the user. In Figure 6, orange arrows show the orientation of each visualization in each layout [13].

Height is another dimension referring to the vertical space between small multiples without changing the aspect ratio [13].

Detail level is for creating an exploded view of small multiples that allow users to adjust the level of semantic detail shown [13].

Interaction is referring to navigating through 3D space, manipulate small multiples, control parameters of a single visualization, and interact with the 3D UI inside the environment. In the following section, we describe this dimension in more detail.

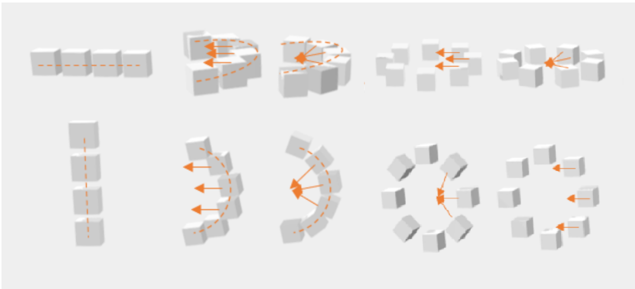

Figure 6: Curving horizontal and vertical 1D layouts of small multiples in semi- and full- circular shapes (each cube represent a visualization).

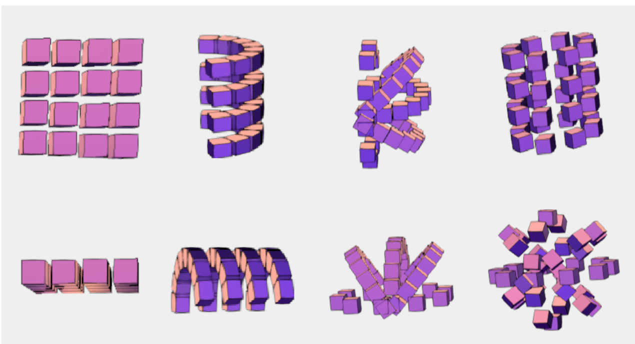

Figure 7: Curving a 2D layout into a cylinder, a semi-cylinder, a sphere, or a semi-sphere layouts.

3.1 Interaction with immersive data visualization

Interaction is an essential feature of immersive environments that include multiple 3D data visualizations, as users must be able to navigate through 3D space, manipulate small multiples, control parameters of a single visualization, and interact with the 3D UI inside the environment. Therefore, we argue that the design space should have interaction techniques as another dimension, because such immersive environments are not static and many tasks can be and needed to be performed on 3D data visualizations, volumetric models, charts and graphs and other visualization techniques that are mentioned in the introduction section. This will make ”interaction” a main factor in placing the visualizations around the user.

Please note that, in order to choose small multiples’ layout appropriately, we must understand the interaction techniques requirements of a specific application. We cannot simply declare one best technique, because the technique that is best for one application might not be optimal for another application with different requirements. Therefore, application developers and domain experts need to understand interaction requirements before the correct layouts can be chosen.

The type of interaction technique usually depends on the task to be performed. Researchers have organized interaction tasks for immersive analytic systems in different ways. For instance, Fonnet et al. [6] took their interaction tasks and sub-categories from the taxonomy of Brehmer and Munzner [5] that includes Navigate, Select, Details on Demand, Arrange, Change, Filter, Aggregate, Annotate, Import, Derive and Record. Kraus et al. [11] classified tasks into higher-level (synoptic) tasks and elementary tasks, based on Andrienko and Andrienko’s task taxonomy [2] resulting in seven categories of analysis task. Synoptic tasks include clustering/classification (Structuring data points), anomaly detection (Finding anomalies, such as outliers in datasets), pattern analysis (Finding trends, repetitions and visual patterns), visual search (visually identify and track an object or data point), and overview (Providing the big picture of a dataset), as well as elementary tasks that are comparative analysis or data enrichment [11].

Table 1: Interaction techniques and corresponding tasks in an immersive environment with small multiples.

Interaction technique	Tasks
Object selection	Pointing, Selection, Viewing.
Object manipulation	Translation, Rotation, Scaling.
Navigation	Moving, Zooming and panning within an environment.
Abstract	Non-spatial interactions such as editing (delete, undo, redo, insert, group, etc.).

Munzner [16] described three levels of actions that define user goals. The high-level choices describe how the visualization is being used to analyze, either to consume (Discover, Present, Enjoy) existing data or to also produce (Annotate, Record, Derive) additional data, the mid-level choices cover what kind of search is involved (Lookup, Locate, Browse, Explore), and the low-level choices pertain to the kind of query (Identify, Compare, Summarize) [16].

Based on the above argument and these tasks’ taxonomies, we can basically divide interaction techniques into four categories: object selection, object manipulation, navigation in virtual environment, and abstract interactions. Table 1 shows theses categories and related tasks for each interaction technique. These interactions can be applied to each individual visualization or small multiples as a whole. In addition, based on devices, and input and output modalities, interaction techniques include aural cues (i.e. speech and paralinguistics), visual cues (i.e. gaze and gesture) and environmental information (i.e. object manipulation, writing and drawing) [3].

For each specific interaction technique, based on the task the user wants to perform on small multiples in an immersive 3D space, we need to identify a layout that fits the application with a good use of space. Therefore we argue that more design choices need to be implemented and empirically evaluated for specific tasks, interaction techniques, visualization techniques, and context.

4 Conclusion and Future Work

Our literature studies revealed that there are different design choices based on the design space proposed in [13] for small multiples layouts. Moreover, we have added height, detail level and interaction techniques to the design space as other important aspects of 3D data visualization layouts. These different design choices for layouts performance have not been tested or evaluated based on evidence. Even if some are the users’ preferred layouts, due to the variety of tasks and the visualization techniques, we argue that there’s a gap in this field. In addition, with a significant increase in the number of multiples, it is an issue that old layouts, such as simple full-circle, make getting an overview at a glance difficult, and therefore more complex layouts might need to be implemented for the better use of the space in an immersive environment. Regarding the issues, some layouts may be preferred by participants but would not necessarily increase the performance of the user during the tasks. Thus we argue that these layouts need to be evaluated via a set of user studies.

There is future opportunity to more thoroughly explore the curvature design space such as the combination of layouts with different aspect ratios and orientations. In addition, we need to evaluate the layouts for specific and suitable tasks with regard to the visualization techniques. In addition, it would be interesting to study the impact of interaction techniques with more evidence based user studies.

REFERENCES

[1] J. Aliprantis, M. Konstantakis, R. Nikopoulou, P. Mylonas, and G. Caridakis. Natural interaction in augmented reality context. In *VIPERC@ IRCDL*, pp. 50–61, 2019.

[2] N. Andrienko and G. Andrienko. *Exploratory analysis of spatial and temporal data: a systematic approach*. Springer Science & Business Media, 2006.

[3] H. Bai, P. Sasikumar, J. Yang, and M. Billinghurst. A user study on mixed reality remote collaboration with eye gaze and hand gesture sharing. In *Proceedings of the 2020 CHI conference on human factors in computing systems*, pp. 1–13, 2020.

[4] J. Bertin. Graphics and graphic information processing. In *Readings in information visualization: using vision to think*, pp. 62–65. 1999.

[5] M. Brehmer and T. Munzner. A multi-level typology of abstract visualization tasks. *IEEE transactions on visualization and computer graphics*, 19(12):2376–2385, 2013.

[6] A. Fonnet and Y. Prie. Survey of immersive analytics. *IEEE transactions on visualization and computer graphics*, 27(3):2101–2122, 2019.

[7] Y. Fujiwara, S. Date, K. Ichikawa, and H. Takemura. A multi-application controller for sage-enabled tiled display wall in wide-area distributed computing environments. *Journal of Information Processing Systems*, 7(4):581–594, 2011.

[8] D. Hayatpur, H. Xia, and D. Wigdor. Datahop: Spatial data exploration in virtual reality. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*, pp. 818–828, 2020.

[9] C. Hurter, N. H. Riche, S. M. Drucker, M. Cordeil, R. Alligier, and R. Vuillemot. Fiberclay: Sculpting three dimensional trajectories to reveal structural insights. *IEEE transactions on visualization and computer graphics*, 25(1):704–714, 2018.

[10] S. Johnson, D. Orban, H. B. Runesha, L. Meng, B. Juhnke, A. Erdman, F. Samsel, and D. F. Keefe. Bento box: An interactive and zoomable small multiples technique for visualizing 4d simulation ensembles in virtual reality. *Frontiers in Robotics and AI*, 6:61, 2019.

[11] M. Kraus, J. Fuchs, B. Sommer, K. Klein, U. Engelke, D. Keim, and F. Schreiber. Immersive analytics with abstract 3d visualizations: A survey. In *Computer Graphics Forum*, vol. 41, pp. 201–229. Wiley Online Library, 2022.

[12] F. C. Y. Li, D. Dearman, and K. N. Truong. Virtual shelves: interactions with orientation aware devices. In *Proceedings of the 22nd annual ACM symposium on User interface software and technology*, pp. 125–128, 2009.

[13] J. Liu, A. Prouzeau, B. Ens, and T. Dwyer. Design and evaluation of interactive small multiples data visualisation in immersive spaces. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 588–597. IEEE, 2020.

[14] W. Luo, A. Lehmann, H. Widengren, and R. Dachselt. Where should we put it? layout and placement strategies of documents in augmented reality for collaborative sensemaking. In *CHI Conference on Human Factors in Computing Systems*, pp. 1–16, 2022.

[15] A. MacEachren, D. Xiping, F. Hardisty, D. Guo, and G. Lengerich. Exploring high-d spaces with multiform matrices and small multiples. In *IEEE Symposium on Information Visualization 2003 (IEEE Cat. No. 03TH8714)*, pp. 31–38. IEEE, 2003.

[16] T. Munzner. *Visualization analysis and design*. CRC press, 2014.

[17] A. Prouzeau, A. Bezerianos, and O. Chapuis. Towards road traffic management with forecasting on wall displays. In *Proceedings of the 2016 ACM International Conference on Interactive Surfaces and Spaces*, pp. 119–128, 2016.

[18] K. A. Satriadi, B. Ens, M. Cordeil, T. Czauderna, and B. Jenny. Maps around me: 3d multiview layouts in immersive spaces. *Proceedings of the ACM on Human-Computer Interaction*, 4(ISS):1–20, 2020.

[19] W. Scheibel, M. Trapp, and J. Döllner. Interactive revision exploration using small multiples of software maps. In *VISIGRAPP (2: IVAPP)*, pp. 133–140, 2016.

[20] B. Spittle, M. Frutos-Pascual, C. Creed, and I. Williams. A review of interaction techniques for immersive environments. *IEEE Transactions on Visualization and Computer Graphics*, 2022.

[21] M. Spur, V. Tourre, E. David, G. Moreau, and P. Le Callet. Exploring multiple and coordinated views for multilayered geospatial data in virtual reality. *Information*, 11(9):425, 2020.

[22] E. R. Tufte. The visual display of quantitative information. *The Journal for Healthcare Quality (JHQ)*, 7(3):15, 1985.

[23] D. Vohl, D. G. Barnes, C. J. Fluke, G. Poudel, N. Georgiou-Karistianis, A. H. Hassan, Y. Benovitski, T. H. Wong, O. L. Kaluza, T. D. Nguyen, et al. Large-scale comparative visualisation of sets of multidimensional data. *PeerJ Computer Science*, 2:e88, 2016.