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# The Value of Immersive Visualization

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*In recent years, research on immersive environments has experienced a new wave of interest, and immersive analytics has been established as a new research field. Every year, a vast amount of different techniques, applications, and user studies are published that focus on employing immersive environments for visualizing and analyzing data. Nevertheless, immersive analytics is still a relatively unexplored field that needs more basic research in many aspects and is still viewed with skepticism. Rightly so, because in our opinion, many researchers do not fully exploit the possibilities offered by immersive environments and, on the contrary, sometimes even overestimate the power of immersive visualizations. Although a growing body of papers has demonstrated individual advantages of immersive analytics for specific tasks and problems, the general benefit of using immersive environments for effective analytic tasks remains controversial. In this article, we reflect on when and how immersion may be appropriate for the analysis and present four guiding scenarios. We report on our experiences, discuss the landscape of assessment strategies, and point out the directions where we believe immersive visualizations have the greatest potential.*

Immersive Analytics (IA) is the research on analyses concerned with the "use of engaging, embodied analysis tools to support data understanding and decision making".[1] Such "engaging tools" include augmented reality (AR) and virtual reality (VR) devices. Over the last decade, IA has gained attention in the scientific community, particularly in the areas of visualization and human–computer interaction. There have been repeatedly times in the past when research on immersive environments has been particularly intense.[3] The recent surge may be due to the technological advancements in consumer-ready head-mounted AR and VR displays, as well as the stronger inclusion of the analytical process in such environments. Even though more and more research is being produced each year, the field as a whole is still relatively unexplored. Fast-paced technological progress means that research is targeted at research subjects that are rapidly changing. Findings and conclusions that apply to one device may not be applicable to another device that has a higher resolution, a wider field of view, or any other change that improves the immersive experience.

Although IA aims at multisensory interfaces, the focus is often on vision. Immersive visualizations are tools that can enable efficient and effective immersive analytics procedures to extract knowledge from data. With that, immersive visualization can be seen as a fundamental component of immersive analytics. Most researchers now agree that IA is not a panacea that overcomes all issues associated with 3-D visualizations on screens and makes unfavorable 3-D visualizations suddenly useful. The underlying drawbacks of these 3-D visualizations,[12] such as occlusion, remain even when viewed in an immersive environment. Nevertheless, we have the impression that many IA studies are conducted with abstract 3-D visualizations, such as scatterplots, without comprehensive justification. In some cases, even 3-D visualization variants that are generally believed to perform worse than 2-D counterparts are compared based on their performance on different media such as screen vs. AR/VR. That is, many studies use abstract 3-D visualizations in immersive environments which have already been shown to perform poorly in the past, rather than shifting the focus to other visualizations and application domains that are much more likely to actually lead to advantages in immersive environments compared to classic 2-D screen setups.

This and similar circumstances have led us to question whether many current efforts are heading in directions that do not exploit the full potential of immersive environments. While it is legitimate to revisit and reevaluate previous findings with new devices, the focus should be on approaches that promise the greatest potential in the extended design space. AR and VR offer much more than just a medium for viewing 3-D visualizations, for example, by greatly expanding the design space in terms of multisensory interfaces, interaction, navigation, and collaborative aspects. We define the term immersive analytics very broadly and regard it as an interplay of analytics, visualization, interaction, and multisensory experiences.

*Further reading on immersive Analytics:*

Dwyer *et al.* (2018) https://doi.org/10.1007/978-3-030-01388-2

Given the previous hype periods for certain technologies such as VR and AR, we think it is important to mention the fundamental differences of the current surge, such as the wide availability of affordable, high-quality devices, and the existence of whole software ecosystems and communities which greatly simplify the implementation effort. However, we also like to point out potentially remaining obstacles. These include limitations of both the medium (hardware/software) and the human user. Expanding the range of data representation characteristics, e.g., to a multisensory 3-D representation, is more prone to emphasize group differences and perceptual deficiencies of the human user than the limited classical 2-D visualizations. For instance, stereo blindness or movement deficits may affect analysis or data interpretation. Wearing tethered VR goggles for several workdays could have strong effects on human health and well-being, and thus be prohibited for use in certain work environments.

Based on these considerations, our driving question is the following: Why, when, and how does it make sense to use AR/VR for analysis tasks? First and foremost, we want to make the reader aware of (1) the fact that IA does indeed extend the design space of classic visual analytics, (2) the plethora of opportunities for developing new analysis, visualization, and interaction techniques, (3) potential risks and common pitfalls, and (4) underexplored, yet promising research areas.

Skarbez *et al.*[13] recently outlined a general research agenda for immersive analytics. In this paper, we complement their line of argumentation by presenting four guiding scenarios that illustrate where we believe some of the greatest potential for immersive analytics applications lies and discuss the value of IA. These scenarios were derived from the experience and discussions among the authors. We conclude this paper with a summary of lessons learned, including references to promising research gaps, appeals to avoid common pitfalls, and general remarks on the topic.

## FOUR GUIDING SCENARIOS

We take a look at four scenarios where we believe immersive visualization has the greatest potential. The list is not exhaustive, and there are certainly additional directions that are generally promising.

### Situated Analysis

*Scenario:* AR fosters the presentation of situated visualizations, that is, the embedding of visualizations in the real environment close to the object of their content. Due to the proximity of the information to the object it refers to, the connection can be easily understood. Embedding visual information directly into its physical context is usually not possible with classical user interface setups. The approach implicitly follows the principle of "details on demand," as the data space is continuously filtered for information that is displayable in the user's field of view. Thus, only information that is potentially interesting to the user at a given location is displayed. While glyphs could serve as initial visualizations to provide a good overview, users could be allowed to interact with them to dive into even more details.

*Examples*: A common example is the display of nutritional information as a bar chart or glyph visualization above each item in a grocery store, as illustrated by ElSayed *et al.*[2] An example of what this might look like is shown in Figure 1. Also quite popular is the dynamic placement of labels in AR space. For example, Zollmann *et al.*[15] use AR to place labels next to buildings to provide users with additional information about their surroundings. Additionally, situated visualizations could also be used to support user


**FIGURE 1.** Situated visualizations that display custom quality scores for each product on a grocery store shelf.

navigation, for example, by displaying a trail on the floor that leads to the desired shelf in a library.

*Reflections:* Situated visualizations and therewith facilitated situated analyses are certainly a big selling point of AR. The possibilities are almost endless once the technology is more mature and AR is widely accessible and used by the public. This ranges from advertising to informative and supportive visualizations to situated visualizations for analyzing real-world environments or objects. Of course, this also comes with challenges. For instance, an increasing degree of augmentation can lead to neglecting the real environment and to sensory overload. Additionally, users must trust the program, as it can direct the users' attention and influence their perception.

## Spatial Data and Spatial Tasks

*Scenario:* Analytical procedures that deal with the examination and analysis of spatial data can benefit from immersive environments. Spatial data often has an inherent spatial mapping in 3-D space, whereas for a representation in 2-D, some sort of transformation or abstraction must be applied. Of course, retaining the original structure is a significant advantage over abstraction and depends on the individual data and tasks. However, especially for spatial tasks or when a spatial context such as the natural environment has to be integrated into the motion analysis, the deployment of 3-D visualizations can be useful. Once there is a clear motivation for using 3-D, additional benefits of 3-D visualizations can be exploited in immersive spaces. For example, anyone who has worked with 3-D modeling software knows how difficult it can be to navigate in 3-D space or to select a specific 3-D region using keyboard and mouse. In immersive spaces, such tasks could be achieved more easily by providing direct interaction capabilities in the 3-D space since no translation from the 2-D input space to the 3-D space is required. In addition to the benefit of an expanded, multimodal interaction design space, previous work has shown potential advantages of stereoscopic and immersive devices that could also be exploited, such as enhanced learning performance, memorization, spatial understanding, and orientation.

*Further reading potentially advantageous properties of immersion:*

Bach *et al.* (2018) https://doi.org/10.1109/TVCG.2017.274594101388-2_1
Gutiérrez *et al.* (2007) https://doi.org/10.1097/00042871-200701010-00099
Ragan *et al.* (2010) https://doi.org/10.1162/pres_a_00016
Schuchardt *et al.* (2007) https://doi.org/10.1145/1315184.1315205

***Examples*** Hurter *et al.*'s FiberClay[4] is a framework for exploring 3-D aircraft trajectories in a VR environment (see Figure 2). Exploring the trajectories in an immersive environment allows the analyst to make use of intuitive spatial interactions, e.g., for selection, while preserving the original shape of the trajectories. Additionally, stereoscopic vision helps to distinguish different trajectories and estimate their depth. There are further examples from other domains, for instance, a scenario from the medical domain for analyzing brain scans where a brain or associated data are interactively investigated in 3-D space.[5]

*Reflections:* Particularly for the pairing of spatial data and spatial tasks, the use of AR/VR is often promising. In those cases, there is a clear motivation for

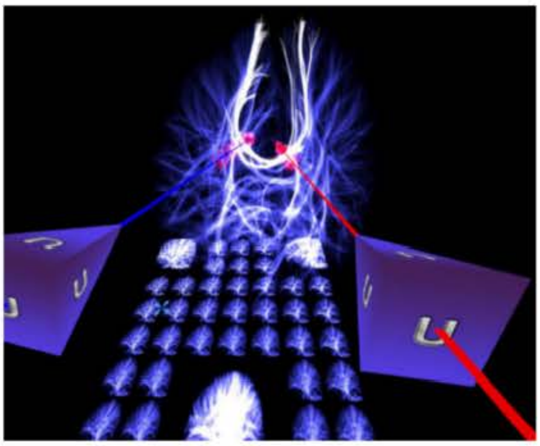

**FIGURE 2.** Analysis of 3-D trajectories in VR[4]. Image courtesy of Christophe Hurter.

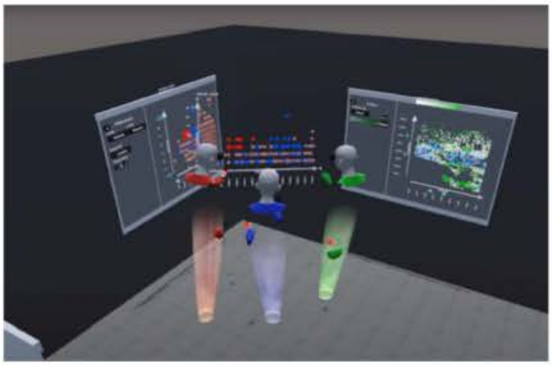

**FIGURE 3.** Collaborative VR environment for the analysis of abstract 2-D and 3-D visualizations.[11] Image courtesy of Benjamin Lee.

visualizing in 3-D, and immersive spaces offer advanced interactions to facilitate spatial tasks in 3-D. However, the need to visualize spatial data in 3-D should be confirmed and first compared with 2-D alternatives. For this scenario, we see the biggest challenge in resisting the temptation to rely on immersive, spatial solutions when better 2-D alternatives exist. Additional challenges with the analysis process itself include difficulties in designing interactions in 3-D space or hardware limitations such as a too low resolution to read text labels properly.

## Collaboration

*Scenario*: Immersive environments offer various advantages when it comes to collaboration. In our opinion, the biggest opportunity for improvement lies in remote collaboration. By using AR/VR, multiple users who are in different physical locations can meet in a shared virtual environment. This gives them a common visual grounding to support their discussion while allowing them to use familiar communication aids such as gestures, facial expressions, and simplified verbal expressions related to relative positions in space (e.g., "here" and "left"). Of course, the extent to which this corresponds to real-world, colocated collaboration experiences is highly dependent on the technical implementation, such as the photorealism of avatars and the achieved embodiment in one's own avatar, e.g., through the perception of one's own body, the provision of a large interaction design space, and haptic feedback.

Another advantage of remote collaboration is scale. For instance, while usually only a limited number of people can stand around a ship's engine, in the virtual environment, a large number of people can simultaneously observe the 3-D model of the engine—even from the exact same location if their avatars are rendered invisible. In addition to the advantages in terms of practicability, interaction, and communication, other social aspects could be exploited in the future. Since user avatars can be designed arbitrarily, it is possible to overcome social inequalities by designing them neutrally in scenarios where this is an issue. There are also possibilities for colocated collaboration, some of which overlap with those for remote collaboration scenarios. For example, when viewing a 3-D visualization, all users can simultaneously investigate the same visualization while constantly seeing where others are. This can improve communication compared to a setup where all users are observing the same visualization but on separate screens.

*Examples:* Lee *et al.*[11] presented Fiesta, a system for collaboration in physically colocated VR environments (see Fig. 3). Multiple users can join a shared VR environment to analyze abstract data visualizations together. The visualizations presented are not necessarily in 3-D, and the VR environment can be used simply as a platform for collaboration without changing the familiar visualization basis. Another use case could be the deployment of immersive environments in teaching scenarios. For example, a real classroom could be replicated in a virtual environment so that students in remote locations can participate in digital lessons and experience them similarly to real classes. Moreover, the use of AR/VR can improve social interactions and communication. In our opinion, the Corona pandemic, in particular, has shown that video chats cannot compete with face-to-face meetings in many respects. Realistic imitations of real meetings using immersive environments could, therefore, have a lot of potential.

*Reflections*: In our opinion, collaborative analysis tasks, in particular in remote collaborations, can certainly benefit from immersive visualizations. Currently, most examples are avatar-based VR applications. There are few examples of AR being deployed for this task, and there are several issues that need to be addressed for better AR-based remote collaboration. For example, AR applications share only a fraction of the overall environment since all collaborators have different real environments, and the display of avatars is a barrier because many AR devices are gesture-based and, therefore, do not have steady information about the position of the arms, making it difficult to display avatars correctly. One of the biggest challenges related to immersive collaboration is its susceptibility to impaired communication due to unwanted artifacts. For example, imperfections in copying participants' gestures and facial expressions can lead to major misunderstandings among collaborators. Sometimes the deliberate suppression of nonverbal expressions can be beneficial. In addition, the

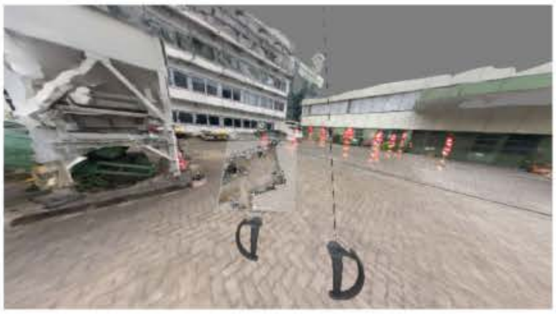

FIGURE 4. Reconstruction of a crime scene is used to vividly present the sequence of events to a court jury.[9]

technology is not yet widespread to be used in everyday life and only participants who have the right hardware can collaborate.

## Presentation

*Scenario*: Immersive environments can be appropriate for simply presenting information—but in a more engaging way. The use of the relatively new and unfamiliar environment is associated with higher levels of excitement, engagement, and entertainment.[6] Such effects certainly help users to keep their attention and internalize information. However, it is not yet clear whether the effect will diminish as the technology becomes more familiar and the "WOW" effect wears off. Another potential benefit of using AR/VR is that it can help users relate familiar measures such as distance, speed, or height to themselves, leading to better estimates of their absolute values. For example, when perceiving the 3-D model of a house, it is easier to estimate its actual size without reference scales in VR than on the screen.[10] The goal of presentation is to convey information as completely and sustainably as possible. Previous studies have shown that immersive environments can support users' (spatial) memory due to more engaging illustrations and spatial anchors (e.g., Kraus *et al.*[8]). Therefore, if this feature can be exploited in a particular presentation scenario, this could be a good motivation for using immersive environments.

*Examples:* For abstract data, spatialization can be useful to exploit the properties mentioned earlier. For instance, Zenner *et al.*[14] presented a way to represent circuit diagrams as 3-D landscapes that can be explored in a VR environment. The authors concluded that although vivid presentation increased user interest, it had no impact on model understanding performance. Another example is the remote access to reconstructed environments, such as museums, construction sites, or excavation areas. Users can walk through the virtual reconstruction of a real environment without having to physically move. For example, in Figure 4, a reconstructed crime scene is shown in a VR environment to vividly convey the course of events in a court trial.[9]

*Reflections*: While, in conventional screen-based analysis environments, a lot of effort is put into increasing the level of engagement through clever user-interface design or even gamification, this already seems to be a side effect in IA. However, it may well be that the effect diminishes with increasing usage. In addition to potential benefits in terms of higher engagement, improved absolute value estimation, and memorization, immersive environments could also be suitable for information presentation during remote site inspections, lectures, or corporate presentations. The three biggest challenges in this scenario are 1) availability, 2) usability, and 3) accessibility. Availability refers to the fact that AR/VR is not yet "common enough" and only a small portion of the population owns AR/VR hardware. By usability, we mean the circumstance that AR/VR is still unfamiliar to many people and many different interaction designs exist, which are often difficult to grasp. Finally, by accessibility, we refer to the challenges inherent to new interaction designs and sensory stimulations, which are not accessible to some people.

# IMPLICATIONS AND DISCUSSION

As illustrated, there are several scenarios where we see great potential for IA applications. In the following, we outline lessons learned, address best practices, and discuss common pitfalls.

*Immerse when it adds value:* Repeatedly, we have come across examples where immersive environments were used seemingly for no reason—just because the technology was new and available. However, when using immersive hardware, there should at least be a hypothesis that promises added value. The actual use of the technology should then be guided by the objective assessment of the added value. The extent to which AR/VR capabilities are exploited must also be carefully considered. It may not make sense to orce the user to walk for spatial navigation or even to perform all analysis steps in an immersive environment just because it is possible. For example, if the IA approach is only beneficial for a specific subtask in an analysis procedure, it may make sense to use hybrid environments where only part of the analysis is done in AR/VR and the rest on a traditional screen.

*IA is not the Holy Grail of 3-D visualization:* A particularly controversial issue is the visualization of abstract

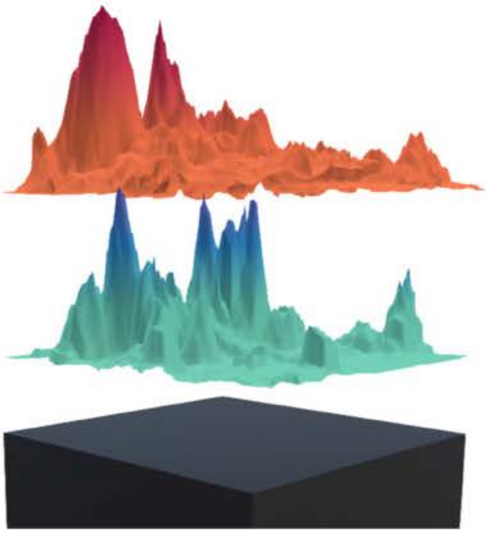

**FIGURE 5.** Abstract data are spatialized, displayed as stacked 3-D heightmaps, and observed in VR for comparative analysis.[8]

data in immersive environments. Although reading 3-D visualizations is improved in some respects when perceived in immersive environments, most of the drawbacks of 3-D visualizations remain; for instance, occlusion, shifted baselines, depth distortions, and the difficulty of estimating and comparing certain visual variables, such as volume, remain major problems. Thus, even if the particular evaluation can show that AR/VR improves the analysis with the 3-D visualization compared to a screen-based setup, it says nothing about the overall merit of AR/VR, as more powerful 2-D alternatives for the screen were simply left out of the comparison (see also the "Straw Man Comparison" pitfall outlined by Munzner[12]).

However, there are certainly specific application areas where it may be useful to spatialize abstract data in order to take advantage of the aforementioned benefits of immersive environments, such as improved spatial understanding, orientation, memorization, or depth perception. For example, in the comparative analysis of 3-D distributions of abstract data, the immersive, spatialized 3-D variant with superpositioned 3-D heatmaps was superior to the juxtapositioned 2-D variant in certain tasks.[8] As shown in Figure 5, the vertical layout combined with the encoding of values on heightmaps facilitates the comparison of the two distributions. The user can slide one distribution through the other to identify correlations, offsets, and general trends. Another example where immersive environments can be useful for abstract data is the integration and exploration of abstract and spatial data, which has been discussed for some time, for example, for applications in life sciences.[7]

In this sense, the use of AR/VR should not be the only motivation for 3-D visualizations. It may be that IA makes 3-D more feasible, but the associated disadvantages must be outweighed by advantages to justify the deployment of the 3-D visualization in question. At this point, it is worth mentioning that IA goes beyond 3-D visualization, and its added value can also be drawn for 2-D visualizations from other aspects, such as multisensory feedback, enhanced interaction modalities, collaboration opportunities, and so on.

*Assess the value of deployed AR/VR environments:* Assessments of added value, as they are often used in practice, can be divided into three main groups. The first and weakest evaluation is that by example. In this case, a certain analytical procedure is performed in an immersive environment to demonstrate its general applicability without directly comparing it to conventional approaches. Usually, the added value is then asserted by argumentative hypotheses.

The second form of assessment is property evaluation. A specific aspect is singled out and compared across different media. An example would be a study comparing the memorability of users observing a visualization on a screen and in VR. While this may provide the most reliable and substantiated evidence, it could depend on many factors that do not apply in a particular application scenario.

The final group of evaluation involves comparisons of immersive and nonimmersive analysis scenarios. This form of assessment can clearly identify the advantages and disadvantages of a particular IA system over the nonimmersive counterpart to which it was compared, but because of many independent variables, the exact reasons are difficult to determine.

We argue that all three types of evaluation have their right to exist. While the first approach provides initial conceptual evidence and new hypotheses, the second approach can quantitatively explore potential merits at a very detailed level. Their applicability and usefulness for a particular analysis use case can then be assessed by means of the third form of evaluation. Especially for the last form of assessment, it is important to ensure that a fair comparison takes place. For example, in most cases, it does not make sense to assume the use of 3-D visualizations when much more powerful 2-D visualizations exist for the given task, and then compare the performance of users working with them on screen and in VR. In case it is assumed that the use of an immersive environment overcomes the disadvantages of the 3-D visualization, the 3-D visualization in VR could be compared with the best possible 2-D visualization on the screen.

*Keep Going:* IA is still a relatively new field that lacks a broad scientific fundament. For instance, often criticized but not sufficiently addressed is the lack of established analysis environments, authoring toolkits, and standards for IA. There have been advances in the compatibility of development frameworks, such as Unity or UnrealEngine. This has reduced the effort required to create new applications for immersive devices compared to previous VR eras, such as during the 1990s, where such development endeavors needed to be much closer to the hardware. However, there is still no end-user-ready visualization system like Tableau for direct manipulation analysis of data, neither is there an established library like D3.js for a unified way to create custom visualizations in immersive environments. Likewise, with regard to interaction modalities, no golden standard—similar to the iconic duo of mouse and keyboard for PCs—has yet emerged among the many options. Every single AR/VR device manufacturer relies on individual controllers and input modalities. Additionally, rapidly evolving hardware leads to the need for continuous re-evaluation. Findings that apply to a CAVE VR environment from the 1980s do not necessarily apply to modern HMD VR setups. As there are many different areas of potentially very useful applications for immersive hardware, even away from IA, we expect the technology to grow in popularity, familiarity, and availability over the long term. And this could make it even more attractive for everyday IA procedures.

## CONCLUSIONS

We believe that there is much potential for IA and that there are ample opportunities for research in this area. In this article, we presented four guiding scenarios to which we attribute great potential of immersive visualizations: situated visualizations, spatial data analysis with spatial tasks, collaboration, and presentation. In addition to examples and justifications for our proposals, we also reflected on the overall situation in the field and pointed out common misconceptions and—in our opinion—best practices. While in this article we focused on immersive visualization, the field of IA is much broader and has much potential in other directions as well. For example, the involvement of different senses, such as through sound or haptics, opens up a whole landscape of different design opportunities for analytic processes. For each individual aspect, the new possibilities bring new challenges, and it is up to research to determine the added value of IA for a given combination of data, task, and user. In the past, there have been several research hypes of immersive technologies that promised great changes—which never occurred to the anticipated extent. Even if there are technological opportunities and improvements, the technology must first be accepted by potential user communities. While it is still unclear when and how immersive technologies will become standard tools for data analysis, there are already strong indicators such as studies with convincing evaluations that show the potential as well as the availability of development platforms, but also software and hardware sales, that let us expect that these technologies might be here to stay this time.

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## REFERENCES

1. T. Chandler *et al.*, "Immersive analytics," in *Proc. Big Data Vis. Anal.*, 2015, pp. 1–8, doi: 10.1109/BDVA.2015.7314296.
2. N. A. M. ElSayed, B. H. Thomas, K. Marriott, J. Piantadosi, and R. T. Smith, "Situated analytics: Demonstrating immersive analytical tools with augmented reality," *J. Vis. Languages Comput.*, vol. 36, pp. 13–23, 2016, doi: 10.1016/j.jvlc.2016.07.006.
3. A. Fonnet and Y. Prie, "Survey of immersive analytics," *IEEE Trans. Vis. Comput. Graphics*, vol. 27, no. 3, pp. 2101–2122, Mar. 1, 2021, doi: 10.1109/tvcg.2019.2929033.
4. 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 Trans. Vis. Comput. Graphics*, vol. 25, no. 1, pp. 704–714, Jan. 2019, doi: 10.1109/TVCG.2018.2865191.
5. S. Jaeger *et al.*, "Challenges for brain data analysis in VR environments," in *Proc. IEEE Pacific Vis. Symp.*, 2019, pp. 42–46, doi: 10.1109/PacificVis.2019.00013.
6. C. Jennett *et al.*, "Measuring and defining the experience of immersion in games," *Int. J. Hum. Comput. Stud.*, vol. 66, no. 9, pp. 641–661, 2008 , doi: 10.1016/j.ijhcs.2008.04.004.
7. A. Kerren and F. Schreiber, "Why integrate InfoVis and SciVis?: An example from systems biology," *IEEE Comput. Graphics Appl.*, vol. 34, no. 6, pp. 69–73, Nov./Dec. 2014, doi: 10.1109/MCG.2014.122.
8. M. Kraus *et al.*, Assessing 2D and 3D heatmaps for comparative analysis: An empirical study," in *Proc. Conf. Hum. Factors Comput. Syst.*, 2020, pp. 1–14, doi: 10.1145/3313831.3376675.

9. M. Kraus *et al.*., "Toward mass video data analysis: Interactive and immersive 4D scene reconstruction," *Sensors*, vol. 20, no. 18, pp. 1–38, 2020, doi: 10.3390/s20185426.
10. B. Lee, D. Brown, B. Lee, C. Hurter, S. Drucker, and T. Dwyer, "Data visceralization: Enabling deeper understanding of data using virtual reality," *IEEE Trans. Vis. Comput. Graphics*, vol. 27, no. 2, pp. 1095–1105, Feb. 2021, doi: 10.1109/tvcg.2020.3030435.
11. B. Lee, X. Hu, M. Cordeil, A. Prouzeau, B. Jenny, and T. Dwyer, "Shared surfaces and spaces: Collaborative data visualisation in a co-located immersive environment," *IEEE Trans. Vis. Comput. Graphics*, vol. 27, no. 2, pp. 1171–1181, Feb. 2021, doi: 10.1109/tvcg.2020.3030450.
12. T. Munzner, "Process and pitfalls in writing information visualization research papers," in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): Bd. 4950 LNCS*, A. Kerren, J. T. Stasko, J.-D. Fekete, and C. North, Eds. Berlin, Germany: Springer-Verlag, 2008, pp. 134–153, doi: 10.1007/978-3-540-70956-5_6.
13. R. Skarbez, N. F. Polys, J. T. Ogle, C. North, and D. A. Bowman, "Immersive analytics: Theory and research agenda," *Front. Robot AI*, vol. 6, 2019, Art. no. 82, doi: 10.3389/frobt.2019.00082.
14. A. Zenner, A. Makhsadov, S. Klingner, D. Liebemann, and A. Krüger, "Immersive process model exploration in virtual reality," *IEEE Trans. Vis. Comput. Graphics*, vol. 26, no. 5, pp. 2104–2114, May 2020, doi: 10.1109/TVCG.2020.2973476.
15. S. Zollmann, C. Poglitsch, and J. Ventura, "VISGIS: Dynamic situated visualization for geographic information systems," in *Proc. Int. Conf. Image Vis. Comput. New Zealand*, 2016, pp. 1–6, doi: 10.1109/IVCNZ.2016.7804440.

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