The Invisible Hand of the Context: Authoring of Context-Aware Mixed Reality Labels

Julian Baader
Interactive Media Lab Dresden
TUD Dresden University of Technology
Dresden, Germany
julian.baader@tu-dresden.de

Mats Ole Ellenberg*
Interactive Media Lab Dresden
TUD Dresden University of Technology
Dresden, Germany
mats_ole.ellenberg@tu-dresden.de

Marc Satkowski
Interactive Media Lab Dresden
TUD Dresden University of Technology
Dresden, Germany
msatkowski@acm.org

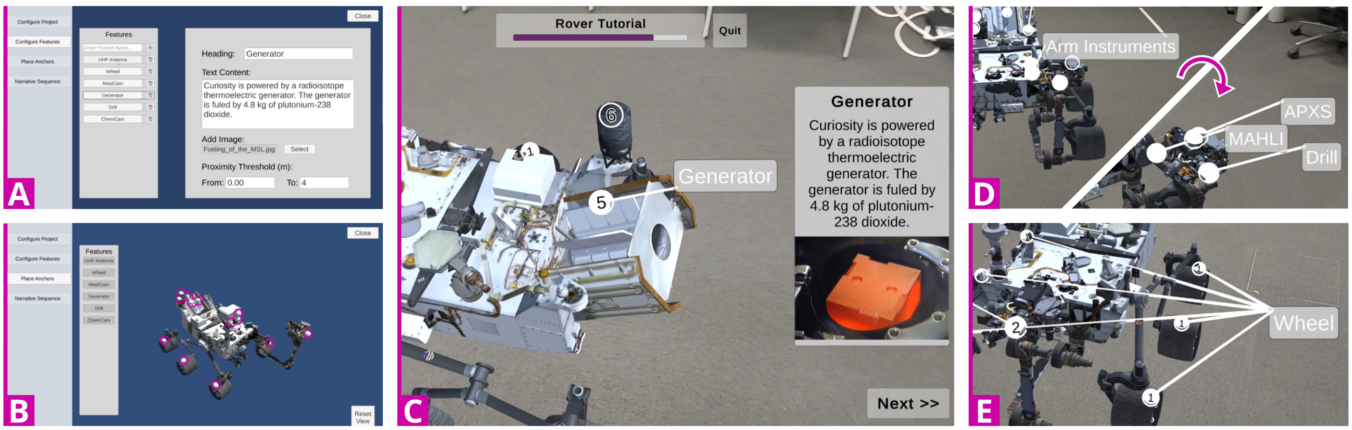

Figure 1: Our developed MR label authoring system consists of (A+B) the desktop-based authoring tool and (C–E) the MR experience application. The authoring tool allows for (A) defining features to present as labels at (B) specified anchor points (highlighted in magenta). In the experience application, users can explore the authored labels through (C) a narrative sequence controllable by UI elements, (D) hierarchical label expansion as the user gets closer to the labels, or (E) the relation of multiple anchor points to one label.

Abstract

Labels, textual annotations attached to virtual or real-world objects, play a crucial role in Mixed Reality (MR) by providing guidance, instruction, and additional information. However, accurately placing and managing labels in MR environments is a challenging problem. Despite extensive research on label placement algorithms, little attention has been given to adapting MR labeling systems for real-world applications or developing accessible authoring tools for non-technical users. To address this gap, this work introduces considerations and concepts for context-aware labeling that go beyond static annotations, incorporating interactive and dynamic label behaviors that adjust to context and user interactions. Furthermore, an intuitive authoring tool was developed that enables users to configure and deploy MR labeling experiences without specialized programming knowledge. This work lays a foundation for more accessible, adaptable, and interactive MR labeling systems by combining context-sensitive MR labeling considerations with practical content creation.

CCS Concepts

• **Human-centered computing → Mixed / augmented reality**; **User interface toolkits**.

Keywords

Mixed Reality, Labeling, Label Authoring, Context Aware Labels, Mixed Reality Labels

ACM Reference Format:
Julian Baader, Mats Ole Ellenberg, and Marc Satkowski. 2025. The Invisible Hand of the Context: Authoring of Context-Aware Mixed Reality Labels. In *Mensch und Computer 2025 (MuC '25), August 31–September 03, 2025, Chemnitz, Germany*. ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3743049.3748552

1 Introduction

MR technology has evolved significantly, blending virtual content with the physical world to create interactive experiences [42]. Head-mounted devices (HMDs), handheld devices, and spatial mapping systems now enable a wide range of applications, from industrial maintenance [14, 52] and technical training [14, 19] to museum exhibits [2, 38] and educational tools [49]. Labeling – annotating objects with additional information [7] – serves multiple functions,

*Also with Centre for Tactile Internet with Human-in-the-Loop (CeTI), TUD Dresden University of Technology

ACM ISBN 979-8-4007-1582-2/25/08
https://doi.org/10.1145/3743049.3748552

such as guiding, informing, or instructing users [7, 28], much like (mostly textual) annotations in traditional maps or diagrams [15, 53]. A major challenge is placing labels optimally in relation to the object, the surrounding space, and the user's perspective. Strategies like leader lines have been explored to address spatial constraints and visibility. While label placement is already complex in 2D spaces, MR introduces additional challenges in dynamically changing 3D environments. Factors such as user perspective, occlusion, environmental complexity, and cognitive load must be considered. Poorly placed labels can cause visual clutter, reduced legibility, or disrupted spatial perception. Effective solutions require algorithms that dynamically adjust label positioning to ensure visibility, minimize occlusion, and maintain temporal coherence [34]. However, despite extensive research on label placement algorithms (esp. for 2D spaces), adaptation to both the user and the specific situation in MR is still underexplored. Furthermore, MR application development is resource-intensive and demands advanced technical skills [29, 37], creating barriers for non-technical users like educators, museum curators, and industrial trainers. Authoring tools [8, 21] aim to simplify content creation but often focus on single use cases or are too generic, limiting accessibility for non-experts. Existing research has made limited progress in developing accessible frameworks for MR labeling.

This work addresses these gaps by exploring *adaptive and context-aware labeling* for MR applications. Two contributions are proposed: **First**, a set of considerations and concepts for labeling MR that extend beyond static annotations to include interactive and adaptive behaviors driven by context and user interaction. **Second**, an authoring tool that translates these concepts into a practical system, enabling non-technical users to define and configure MR labeling experiences without programming expertise. The tool supports deployment across multiple MR platforms, ensuring accessibility and flexibility.

2 Background

Our research goal and contributions are related to two specific research areas, which we want to briefly address in this section.

Label Placement. Labels (also called call-outs [25] or textual annotations [30, 36]) identify and describe elements within visual spaces such as charts [27], maps [53], or diagrams [13]. They can be placed internally, within the object, or externally outside the object, connected to anchor points via leader lines [6, 12]. Due to the NP-hard nature of label placement [35], many automatic approximation techniques have emerged. These range from exact methods like dynamic programming [18] and weighted matching [4] to force-based methods [23] or ML-based approaches [10, 39] for real-time use.

Label placement techniques have also been incorporated in MR environments [3, 5, 50], (interactive) 3D visualizations [45, 48], or volume visualizations [9, 26]. Like traditional labels, MR labels are typically *internal* or *external*, and positioned in either *screen space* or *object space* [20, 54]. In screen space, labels are placed based on the 2D projection of anchor points [34], using techniques similar to traditional layouts. In object space, labels are anchored in 3D and follow the associated objects as the user's view or scene changes [50]. To maintain readability, such labels often rotate to face the user [25, 50] (i.e., billboarding). However, the dynamic nature of MR scenes can lead to visual issues such as occlusions, overlap, or labels moving out of view. Recalculating label layouts every frame can reduce performance and disrupt label-object associations [3, 34]. To address this, strategies like discrete updates [16, 34, 50] and smooth transitions between placements [16, 34] are commonly used, improving temporal coherence.

Authoring Tools for MR.. Creating MR applications is a complex process that requires programming expertise [1, 29, 37]. This has led to the development of authoring tools designed to make MR content creation more accessible to non-technical users [8]. Nebeling and Speicher [37] highlight a trade-off between simplicity and capability: powerful tools like the Unity game engine require expertise, while simpler, specialized tools lack advanced features. Authoring platforms range from desktop-based tools [33, 41] to mobile and hybrid approaches that offer better contextual feedback [51]. Fully immersive systems like the training tool for industrial procedures of Skreinig et al. [46] further reduce the gap between creation and deployment environments. However, challenges persist in adapting content across devices [24, 47] and ensuring efficient workflows as long compilation times remain a key bottleneck [8]. The authoring tool by Rau et al. [40] addresses the authoring of labels. However, their tool focuses on static content.

Adaptive and Context-Aware MR Interfaces. As MR environments are inherently dynamic and context dependent [43], virtual content must adapt itself accordingly. Adaptive MR interfaces address the challenges of *when*, *where*, and *how* to present information in response to changing user and environmental conditions [11, 17, 32]. For instance, 2D UI elements can be repositioned based on environmental and social cues [31] or their proximity to the user [44], while Han et al. [22] focus on blending virtual content onto physical objects within the user's environment. Labeling is an example of such an adaptive, context-aware MR interface that describes a specific object. In contrast to the previously described work, our approach to making labels adaptive doesn't focus primarily on positioning. Rather, it focuses on structuring label presentation to improve communication of information.

3 Adaptive and Context-Aware MR Labels

Aiming for *adaptive and context-aware labeling* in MR environments leads to inherent dynamic behavior of the labels, their content, and their layouts. More specifically, based on design experience and insights from related work, we see a clear relation (see Fig. 2) between the context (Sec. 3.1) and how it is defined, the adaptations (Sec. 3.2) the MR application can apply to the given content, and the trigger (Sec. 3.3) that combines both together.

3.1 Defining Label Context

To achieve a *context-aware* MR label system, it is necessary to describe what the context actually is. While current MR systems are able to record and sense several different values of the user and the environment, we more specifically want to focus on two specific categories: user properties and content properties, as well as their potential combination.

User Properties. We see two types of user properties relevant for MR label system. First are properties that can be dynamically

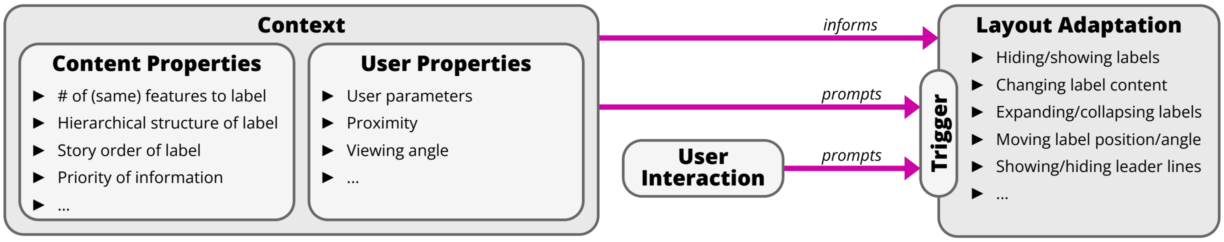

Figure 2: An overview of the relation of context and layout adaptations. Generally, how a label layout looks like can be informed by the context the labeled model is currently in, including the content and the user properties. Furthermore, the context but also specific user interactions can be used to trigger a dynamic adaptation of the currently visible layout.

altered while the user experiences the MR application. Most importantly, these include the proximity or the viewing angle of the user to the labeled entity or its labels. These can also be described as implicit interactions, which manipulate the layout without being the user's specific goal. Second, we could also make use of more traditional user properties, like the user's expertise or their role. These, however, are fixed for a given session and inform the initial content or layout that the user is presented with.

Content Properties. The content or the entity that is labeled also provides properties relevant for an MR label system. These include (1) the entity features to label, (2) the priority of a given information, (3) the hierarchical structure of label content, (4) the narrative order of content, or (5) the number of features that can be related to one label.

Combined Properties. While both types of properties can be used individually to define the context, they can also be used to create a new combined property. To give an example, the *viewing angle* and the *features to be labeled* can be combined to define which features are currently *occluded* through the user's current perspective.

3.2 Layout Adaptations

MR systems are inherently dynamic, making it important to consider which visual parameter to adapt to optimize the communication of information and support exploration. These adaptations can encompass a range of modifications, including hiding or showing labels, altering label content, and expanding or collapsing elements to reveal or conceal detail. Further adaptations involve manipulating virtual elements like their position, rotation, or scale, and visibility of connecting leader lines.

3.3 Adaptation Trigger

Lastly, it is also necessary to consider when an adaptation is triggered. The simplest option is to always adapt based on any context change. However, this constant repositioning is mentally rather taxing and can reduce user performance [3, 34]. Other options can be to update in given intervals, if "enough" change has accumulated, or the user is currently not engaged with the shown content. Lastly, the most direct trigger can be an explicit interaction (e.g., touching a label) from the user. Also an implicit interaction like moving can be considered (see Sec. 3.1).

4 Examplary MR Label Concepts

To illustrate the interplay of the previously described considerations, we will present some example concepts for adaptive MR labeling.

Narrative Sequence. In this example, the logical order of the label and the specific position of the user are used. Initially, only the whole entity has one external text label, while many internal labels with numbers are shown. As soon as the user interacts with this label, the narrative sequence is initiated. The first feature is now labeled externally with a more detailed description. As the user now interacts (e.g., pressing a next button) with the system, the current label collapses again, while the next number will be expanded (see Fig. 1C).

Multi-Anchored Labels. In this example, the number of features with the same label is used, while the viewing direction informs the trigger. As a default, only one label, which is connected through a leader line to one of the many features, is presented. As the user walks around, another, more optimal feature is selected, and the source of the leader line is changed to this particular feature. As the user wants to see which parts of the labeled entity are labeled the same, they interact with the system (e.g., hold down a button) to temporarily see all leader lines (see Fig. 1E).

Semantic Label Grouping. In this example, the hierarchical information of the label is used, while the proximity is used to inform the trigger. At a far distance, only the highest level of label groups is shown, which reduces visual clutter by clustering related labels together, as expressed by their hierarchical structure. As the user moves closer, the underlying components appear, while the previously shown group-labels are hidden (see Fig. 1D). At close range, detailed component labels are revealed for finer granularity.

5 Authoring of MR Labels

Following our considerations, we will describe our developed prototype (Sec. 5.1) and its two components, and depict how a workflow using our system looks like (Sec. 5.2). The prototypes, the projects described in the workflow, as well as a video of the same can be found in the supplemental material.

5.1 System Description

To enable an easy configuration of MR labels, especially making them adaptive, and to facilitate their exploration, we developed an openly available prototype[1]. It consists of two major components: the authoring tool itself (see Fig. 1A+B), and an experience application (see Fig. 1C-E) that runs on the target devices (i.e., the Meta Quest 3 and a handheld Android device). Both are standalone applications that were implemented using Unity3D game engine. While many label behaviors are manually authored (i.e., content properties), certain runtime functionalities (i.e., triggers), such as label placement algorithms and platform-specific interaction modalities, are managed by the experience application.

In practice, labeling a real-world object requires the system to accurately track its position and orientation, aligning it with a corresponding virtual representation. However, since object tracking falls outside the scope of this work, the developed prototype focus exclusively on labeling purely virtual objects. This is merely a technical restriction, and all of the previously discussed considerations and concepts apply equally to real models. Similarly, while label placement algorithms play a crucial role in maintaining clarity and usability, this work does not aim to develop novel algorithmic approaches for label positioning.

Authoring Tool. The authoring tool was implemented as a desktop-based system that allows creators to define how labels appear, behave, and adapt to various user scenarios without the need for scripting or coding skills. The authoring tool's core functionality encompasses: project and model management, feature and additional content definition (see Fig. 1A), positioning of anchor points (see Fig. 1B), and organizing labels for a narrative presentation mode.

A key requirement of the system was cross-platform interoperability. Projects created using the authoring tool are saved in a device-independent format with a simple folder structure, including a JSON file containing project-specific settings. This allows them to be transferred to target devices without requiring compilation.

Experience Application. The final MR experience interprets the saved data and presents the model and their labels to the user. The experience application is deployable on the Meta Quest 3 and handheld Android devices. While the two device types share core functionalities such as anchor point selection and label placement, they differ in interaction paradigms and input methods due to the unique characteristics of each device.

5.2 Exemplary Workflow

We use a step-by-step presentation of components of the Curiosity Mars Rover as an example of an authoring workflow. To start, a new project is created, named, and a 3D model of the Mars Rover is loaded. Then, the model's dimensions are adjusted to match those of its real-world counterpart or a scaled replica. Next, various content properties (see Sec. 3.1) are defined (e.g., "Generator") by creating a feature. There we add a descriptive text (see Fig. 1A), a proximity range (see Fig. 1A), and an image (see Fig. 1C). Every feature also needs to be assigned anchor points (see Fig. 1B). For larger features or repeated components, several anchor points can be defined to enable the *multi-anchored labels* concept. In our case, an anchor is assigned to each of the rover's six wheels. Lastly, a narrative sequence is created by naming, ordering and activating it.

[1]Github Repository: https://github.com/imldresden/label-authoring-toolkit

After the project folder has been transferred to the target device, the experience application can be launched and the "Rover Tutorial" project can be loaded. The rover is placed on the floor in a room and can be explored freely or, when selected, in a sequential manner. Here, additional information for the labels will be displayed in a related panel at the appropriate step of the narrative sequence, explorable through the UI buttons, such as seen for the "Generator" in Fig. 1C. When exploring freely, interaction with the labels will open the appropriate panel (see Sec. 3.3). As visualized in Fig. 1E, interaction can also highlight the relation of multiple anchor points (e.g., all wheels) to one label. Depending on the proximity ranges set during authoring, the corresponding labels of features are hidden when moving further away from them, or shown again when approaching (see Fig. 1D).

6 Discussion, Future Work, and Conclusion

In this work, we presented an exploration of *adaptive and context-aware labeling* for immersive environments. More specifically, we described considerations and concepts of such labeling behavior. We developed our prototype system aimed at non-experts, improving upon previous, less context-aware approaches and addressing the complexity of current authoring tools for label placement. Although internal testing indicates that the system is promising, systematic evaluations with content creators and end users are necessary. Future studies should examine how easily non-technical users can create MR experiences and how end users interact with labels, focusing on usability, cognitive load, and learning outcomes to guide further refinements. This should allow us and future researchers to extend and fine-tune our proposed considerations. One major limitation of our current prototype is the missing real-world object tracking. Especially for use cases like museums, education, or industrial training, it will be highly beneficial to align the labeled virtual model to its real-world counterparts, as it can enhance engagement and learning outcomes. To achieve that, two things are necessary: (1) an accurate representation of the real-world objects or even environments within the authoring system (i.e., digital twin) and (2) a precise tracking of the real world to position the labels appropriately, achievable through computer vision and reconstruction techniques. Another limitation of the prototype lies within its limited configurations for labels and their leader lines (e.g., no color, no line texture).

Overall, we believe that our openly available prototype allows for a starting point to explore and investigate the relation between context and label placement further, while the presented consideration provides a framework for this exploration. Generally, the interplay between (authored) context and user interaction, which triggers layout adaptations, already improves upon static MR labeling by making label exploration and its storytelling more immersive and meaningful.

Acknowledgments

Funded by the German Research Foundation (DFG, Deutsche Forschungsgemeinschaft) as part of Germany's Excellence Strategy – EXC 2050/1 – Project ID 390696704 – Cluster of Excellence "Centre for Tactile Internet with Human-in-the-Loop" (CeTI) of Technische Universität Dresden.

References

[1] Narges Ashtari, Andrea Bunt, Joanna McGrenere, Michael Nebeling, and Parmit K. Chilana. 2020. Creating Augmented and Virtual Reality Applications: Current Practices, Challenges, and Opportunities. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3313831.3376722

[2] Rania Raouf Awadalla. 2023. The Application of Mixed Reality Technology as Innovative Approach in Museums. *Journal of Design Sciences and Applied Arts* 4, 2 (June 2023), 275–283. doi:10.21608/jdsaa.2023.192222.1254

[3] R. Azuma and C. Furmanski. 2003. Evaluating Label Placement for Augmented Reality View Management. In *The Second IEEE and ACM International Symposium on Mixed and Augmented Reality, 2003. Proceedings.* 66–75. doi:10.1109/ISMAR.2003.1240689

[4] Michael A. Bekos, Michael Kaufmann, Martin Nöllenburg, and Antonios Symvonis. 2010. Boundary Labeling with Octilinear Leaders. *Algorithmica* 57, 3 (July 2010), 436–461. doi:10.1007/s00453-009-9283-6

[5] Blaine Bell, Steven Feiner, and Tobias Höllerer. 2001. View Management for Virtual and Augmented Reality. In *Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology*. Association for Computing Machinery, New York, NY, USA, 101–110. doi:10.1145/502348.502363

[6] B Bell, S Feiner, and T Höllerer. 2005. Maintaining Visibility Constraints for View Management in 3D User Interfaces. In *Multimodal Intelligent Information Presentation*. Springer, 255–277.

[7] Zahra Borhani, Prashast Sharma, and Francisco R. Ortega. 2024. Survey of Annotations in Extended Reality Systems. *IEEE Transactions on Visualization and Computer Graphics* 30, 8 (Aug. 2024), 5074–5096. doi:10.1109/TVCG.2023.3288869

[8] Jack Brett and Charlie Hargood. 2023. Authoring Tools for Mixed Reality. In *NHT'23 Workshop at ACM Hypertext 2023*. Rome.

[9] S. Bruckner and M.E. Groller. 2005. VolumeShop: An Interactive System for Direct Volume Illustration. In *VIS 05. IEEE Visualization, 2005.* 671–678. doi:10.1109/VISUAL.2005.1532856

[10] Zhutian Chen, Daniele Chiappalupi, Tica Lin, Yalong Yang, Johanna Beyer, and Hanspeter Pfister. 2024. RL-LABEL: A Deep Reinforcement Learning Approach Intended for AR Label Placement in Dynamic Scenarios. *IEEE Transactions on Visualization and Computer Graphics* 30, 1 (Jan. 2024), 1347–1357. doi:10.1109/TVCG.2023.3326568

[11] Yifei Cheng, Yukang Yan, Xin Yi, Yuanchun Shi, and David Lindlbauer. 2021. SemanticAdapt: Optimization-based Adaptation of Mixed Reality Layouts Leveraging Virtual-Physical Semantic Connections. In *The 34th Annual ACM Symposium on User Interface Software and Technology*. Association for Computing Machinery, New York, NY, USA, 282–297. doi:10.1145/3472749.3474750

[12] Ladislav Čmolík, Václav Pavlovec, Hsiang-Yun Wu, and Martin Nöllenburg. 2022. Mixed Labeling: Integrating Internal and External Labels. *IEEE Transactions on Visualization and Computer Graphics* 28, 4 (April 2022), 1848–1861. doi:10.1109/TVCG.2020.3027368

[13] Christoph Daniel Schulze, Yella Lasch, and Reinhard von Hanxleden. 2016. Label Management: Keeping Complex Diagrams Usable. In *2016 IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC)*. 3–11. doi:10.1109/VLHCC.2016.7739657

[14] Lucie Denisart, Javier F. Troncoso, Emilie Loup-Escande, and Alejandro A. Franco. 2024. Breaking down the Barriers between the Digital and the Real: Mixed Reality Applied to Battery Manufacturing R&D and Training. doi:10.26434/chemrxiv-2023-q0vnf-v2

[15] Ugur Dogrusoz, Konstantinos G. Kakoulis, Brendan Madden, and Ioannis G. Tollis. 2007. On Labeling in Graph Visualization. *Information Sciences* 177, 12 (June 2007), 2459–2472. doi:10.1016/j.ins.2007.01.019

[16] Semir Elezovikj, Jianqing Jia, Chiu C. Tan, and Haibin Ling. 2023. PartLabeling: A Label Management Framework in 3D Space. *Virtual Reality & Intelligent Hardware* 5, 6 (Dec. 2023), 490–508. doi:10.1016/j.vrih.2023.06.004

[17] João Marcelo Evangelista Belo, Mathias N. Lystbæk, Anna Maria Feit, Ken Pfeuffer, Peter Kán, Antti Oulasvirta, and Kaj Grønbæk. 2022. AUIT – the Adaptive User Interfaces Toolkit for Designing XR Applications. In *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology*. Association for Computing Machinery, New York, NY, USA, 1–16. doi:10.1145/3526113.3545651

[18] Andreas Gemsa, Jan-Henrik Haunert, and Martin Nöllenburg. 2015. Multirow Boundary-Labeling Algorithms for Panorama Images. *ACM Trans. Spatial Algorithms Syst.* 1, 1 (July 2015), 1:1–1:30. doi:10.1145/2794299

[19] Mar Gonzalez-Franco, Rodrigo Pizarro, Julio Cermeron, Katie Li, Jacob Thorn, Windo Hutabarat, Ashutosh Tiwari, and Pablo Bermell-Garcia. 2017. Immersive Mixed Reality for Manufacturing Training. *Frontiers in Robotics and AI* 4 (Feb. 2017), 3. doi:10.3389/frobt.2017.00003

[20] Timo Götzelmann, Kamran Ali, Knut Hartmann, and Thomas Strothotte. 2005. *Form Follows Function: Aesthetic Interactive Labels.* The Eurographics Association.

[21] Kevin Groh. 2024. What is an Authoring Tool? | Comparison & Examples [Guide]. *Valamis* (July 2024). https://www.valamis.com/hub/authoring-tool Accessed 2025-01-22..

[22] Violet Yinuo Han, Hyunsung Cho, Kiyosu Maeda, Alexandra Ion, and David Lindlbauer. 2023. BlendMR: A Computational Method to Create Ambient Mixed Reality Interfaces. *Proc. ACM Hum.-Comput. Interact.* 7, ISS (Nov. 2023), 436:217–436:241. doi:10.1145/3626472

[23] Knut Hartmann, Kamran Ali, and Thomas Strothotte. 2004. Floating Labels: Applying Dynamic Potential Fields for Label Layout. In *Smart Graphics*, Andreas Butz, Antonio Krüger, and Patrick Olivier (Eds.). Springer, Berlin, Heidelberg, 101–113. doi:10.1007/978-3-540-24678-7_10

[24] Christoph Holtmann and Selina Wernike. 2023. Extended Reality Authoring System for Creating Immersive Experiences: A Requirements Analysis. In *Proceedings of the 20th International Conference on Culture and Computer Science: Code and Materiality*. Association for Computing Machinery, New York, NY, USA, 1–9. doi:10.1145/3623462.3624632

[25] Robin Horst, Anika Degreif, Marvin Mathy, and Ralf Dörner. 2019. Virtual Reality Callouts - Demonstrating Knowledge With Spatial-Related Textual Information. *Computer Graphics and Visual Computing (CGVC)* (2019), 7 pages. doi:10.2312/CGVC.20191252

[26] Zhengang Jiang, Yukitaka Nimura, Yuichiro Hayashi, Takayuki Kitasaka, Kazunari Misawa, Michitaka Fujiwara, Yasukazu Kajita, Toshihiko Wakabayashi, and Kensaku Mori. 2013. Anatomical Annotation on Vascular Structure in Volume Rendered Images. *Computerized Medical Imaging and Graphics* 37, 2 (March 2013), 131–141. doi:10.1016/j.compmedimag.2013.03.001

[27] Stephen M. Kosslyn. 1989. Understanding Charts and Graphs. *Applied Cognitive Psychology* 3, 3 (1989), 185–225. doi:10.1002/acp.2350030302

[28] Benjamin Lee, Michael Sedlmair, and Dieter Schmalstieg. 2024. Design Patterns for Situated Visualization in Augmented Reality. *IEEE Transactions on Visualization and Computer Graphics* 30, 1 (Jan. 2024), 1324–1335. doi:10.1109/TVCG.2023.3327398

[29] Gun A. Lee, Gerard J. Kim, and Mark Billinghurst. 2005. Immersive Authoring: What You eXperience Is What You Get (WYXIWYG). *Commun. ACM* 48, 7 (July 2005), 76–81. doi:10.1145/1070838.1070840

[30] Christine Lehmann and Jürgen Döllner. 2013. Annotating 3D Content in Interactive, Virtual Worlds. In *Proceedings of the 18th International Conference on 3D Web Technology*. Association for Computing Machinery, New York, NY, USA, 67–70. doi:10.1145/2466533.2466552

[31] Zhipeng Li, Christoph Gebhardt, Yves Inglin, Nicolas Steck, Paul Streli, and Christian Holz. 2024. SituationAdapt: Contextual UI Optimization in Mixed Reality with Situation Awareness via LLM Reasoning. In *Proceedings of the 37th Annual ACM Symposium on User Interface Software and Technology*. Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3654777.3676470

[32] David Lindlbauer, Anna Maria Feit, and Otmar Hilliges. 2019. Context-Aware Online Adaptation of Mixed Reality Interfaces. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology*. Association for Computing Machinery, New York, NY, USA, 147–160. doi:10.1145/3332165.3347945

[33] Blair MacIntyre, Maribeth Gandy, Steven Dow, and Jay David Bolter. 2004. DART: A Toolkit for Rapid Design Exploration of Augmented Reality Experiences. In *Proceedings of the 17th Annual ACM Symposium on User Interface Software and Technology*. Association for Computing Machinery, New York, NY, USA, 197–206. doi:10.1145/1029632.1029669

[34] Jacob Boesen Madsen, Markus Tatzgern, Claus B. Madsen, Dieter Schmalstieg, and Denis Kalkofen. 2016. Temporal Coherence Strategies for Augmented Reality Labeling. *IEEE Transactions on Visualization and Computer Graphics* 22, 4 (April 2016), 1415–1423. doi:10.1109/TVCG.2016.2518318

[35] Joe Marks and Stuart Shieber. 1991. *The Computational Complexity of Cartographic Label Placement.* Technical Report TR-05-91. Harvard University, Computer Science Group.

[36] Konrad Mühler and Bernhard Preim. 2009. Automatic textual annotation for surgical planning. In *International Symposium on Vision, Modeling, and Visualization.* https://www.vismd.de/wp-content/uploads/legacy/muehler_2009_vmv.pdf Accessed 2024-09-26..

[37] Michael Nebeling and Maximilian Speicher. 2018. The Trouble with Augmented Reality/Virtual Reality Authoring Tools. In *2018 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. 333–337. doi:10.1109/ISMAR-Adjunct.2018.00098

[38] David A. Plecher, Maximilian Wandinger, and Gudrun Klinker. 2019. Mixed Reality for Cultural Heritage. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, Osaka, Japan, 1618–1622. doi:10.1109/VR.2019.8797846

[39] Jingwei Qu, Pingshun Zhang, Enyu Che, Yinan Chen, and Haibin Ling. 2025. Graph Transformer for Label Placement. *IEEE Transactions on Visualization and Computer Graphics* 31, 1 (2025), 1257–1267. doi:10.1109/TVCG.2024.3456141

[40] Linda Rau, Dagny C. Döring, Robin Horst, and Ralf Dörner. 2022. Pattern-Based Augmented Reality Authoring Using Different Degrees of Immersion: A Learning Nugget Approach. *Frontiers in Virtual Reality* 3 (March 2022). doi:10.3389/frvir.2022.841066

[41] Benjamin Reynolds, Hisham Bedri, Valentin Heun, Anna Fusté, and Christian Vazquez. 2019. Remote Spatial Programming and Collaboration Using a Real-Time Volumetric Capture Space. In *ACM SIGGRAPH 2019 Virtual, Augmented, and Mixed Reality*. Association for Computing Machinery, New York, NY, USA, 1.

doi:10.1145/3306449.3328821

[42] Somaiieh Rokhsaritalemi, Abolghasem Sadeghi-Niaraki, and Soo-Mi Choi. 2020. A Review on Mixed Reality: Current Trends, Challenges and Prospects. *Applied Sciences* 10, 2 (Jan. 2020), 636. doi:10.3390/app10020636

[43] Marc Satkowski. 2024. *Understanding Immersive Environments for Visual Data Analysis*. Ph. D. Dissertation. https://nbn-resolving.org/urn:nbn:de:bsz:14-qucosa2-889954

[44] Marc Satkowski, Rufat Rzayev, Eva Goebel, and Raimund Dachselt. 2022. ABOVE & BELOW: Investigating Ceiling and Floor for Augmented Reality Content Placement. In *2022 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. 518–527. doi:10.1109/ISMAR55827.2022.00068

[45] Jiangfeng She, Xinchi Li, Junyan Liu, Yaqian Chen, Junzhong Tan, and Guoping Wu. 2019. A Building Label Placement Method for 3D Visualizations Based on Candidate Label Evaluation and Selection. *International Journal of Geographical Information Science* 33, 10 (Oct. 2019), 2033–2054. doi:10.1080/13658816.2019.1606431

[46] Lucchas Ribeiro Skreinig, Peter Mohr, Blanca Berger, Markus Tatzgern, Dieter Schmalstieg, and Denis Kalkofen. 2024. Immersive Authoring by Demonstration of Industrial Procedures. In *2024 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, Bellevue, WA, USA, 1293–1302. doi:10.1109/ISMAR62088.2024.00146

[47] Maximilian Speicher, Brian D. Hall, Ao Yu, Bowen Zhang, Haihua Zhang, Janet Nebeling, and Michael Nebeling. 2018. XD-AR: Challenges and Opportunities in Cross-Device Augmented Reality Application Development. *Proc. ACM Hum.-Comput. Interact.* 2, EICS (June 2018), 7:1–7:24. doi:10.1145/3229089

[48] Thierry Stein and Xavier Décoret. 2008. Dynamic Label Placement for Improved Interactive Exploration. In *Proceedings of the 6th International Symposium on Non-photorealistic Animation and Rendering*. Association for Computing Machinery, New York, NY, USA, 15–21. doi:10.1145/1377980.1377986

[49] Satrio Pradono Suryodiningrat, Arief Ramadhan, Harjanto Prabowo, Harry Budi Santoso, and Tsukasa Hirashima. 2024. Mixed Reality Systems in Education: A Systematic Literature Review. *Journal of Computers in Education* 11, 3 (Sept. 2024), 855–878. doi:10.1007/s40692-023-00281-z

[50] Markus Tatzgern, Denis Kalkofen, Raphael Grasset, and Dieter Schmalstieg. 2014. Hedgehog Labeling: View Management Techniques for External Labels in 3D Space. In *2014 IEEE Virtual Reality (VR)*. 27–32. doi:10.1109/VR.2014.6802046

[51] Zeyu Wang, Cuong Nguyen, Paul Asente, and Julie Dorsey. 2021. DistanciAR: Authoring Site-Specific Augmented Reality Experiences for Remote Environments. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–12. doi:10.1145/3411764.3445552

[52] Zenglei Wang, Shusheng Zhang, and Xiaoliang Bai. 2021. A Mixed Reality Platform for Assembly Assistance Based on Gaze Interaction in Industry. *The International Journal of Advanced Manufacturing Technology* 116, 9 (Oct. 2021), 3193–3205. doi:10.1007/s00170-021-07624-z

[53] Pinhas Yoeli. 1972. The Logic of Automated Map Lettering. *The Cartographic Journal* 9, 2 (Dec. 1972), 99–108. doi:10.1179/000870472787352505

[54] Fan Zhang and Hanqiu Sun. 2005. Dynamic Labeling Management in Virtual and Augmented Environments. In *Ninth International Conference on Computer Aided Design and Computer Graphics (CAD-CG'05)*. 6 pp.–. doi:10.1109/CAD-CG.2005.36