Supporting Spatial Thinking in Augmented Reality Narrative: a Field Study

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Abstract. Immersive augmented reality (AR) is an exciting medium for locative narrative. Immersive AR experiences are largely custom-made and site-specific, however: we lack generic tools that help authors consider interactions between physical layout, viewer perspective, and story progression, for specific sites or for locations unknown to the author. In this paper we evaluate Story CreatAR, a tool that incorporates spatial analysis techniques used in architecture, planning, and social sciences to help authors construct and deploy immersive AR narratives. We worked with three authors over several months, moving from script writing and story graph creation to deployment using the tool. We conduct a thematic analysis of each author's actions, comments, generated artifacts, and interview responses. Authors faced a steep learning curve, sometimes misinterpreting spatial properties, and found it difficult to consider multi-site deployment. Despite these challenges, Story CreatAR helped authors consider the impact of layout on their stories in ways their scripts and graphs did not, and authors identified several additional areas for spatial analysis support, suggesting that tools like Story CreatAR are a promising direction for producing immersive AR narratives. Reflecting on author experiences, we identify a number of features that such tools should provide.

Keywords: space syntax, storytelling, proxemics, Story CreatAR, augmented reality.

1 Introduction

In this paper, we consider how authors write and deploy locative and immersive augmented reality (AR) narratives using *Story CreatAR* [1], an authoring tool

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that uses spatial analysis to *dynamically* place story elements (e.g., characters, audio, objects, and events) in *locative narratives*. We define *immersive AR* as AR facilitated by spatially aware head-worn AR devices (e.g., Magic Leap One [2], Microsoft HoloLens [3]), and *locative narrative* as narratives that incorporate physical environments and navigation into the story. We use *spatial analysis* to refer to space syntax (specifically isovist [4] and convex analysis techniques [5, 6]), proxemics [7], and F-formation theory [8]. Using Story CreatAR, authors specify generic spatial rules and constraints using these techniques, which can be tested in VR using the Oculus Quest 2 [9], and deployed to specific environments in AR using the Microsoft HoloLens 2 [3].

Prior work has contributed a range of tools and guidelines to support AR/VR content creators [10–15] and locative media content creators [16–19]. However, platforms and guidelines for AR/VR content and locative storytelling on handheld devices do not help authors consider how story progression is impacted by viewer perspective, embodied interactions, and the unfolding of the environment through movement. These are compelling aspects of immersive locative AR made possible using head-worn AR devices.

We evaluated Story CreatAR with three authors, who each developed a unique, site-agnostic, immersive AR story that satisfies author-defined spatial constraints. We worked closely with each author to examine how they think about and manage spatial considerations for their story. Each author first created their story script, then created a graph-based representation of a section of the story. Next, the author used Story CreatAR to block out sections of their story.

Our rationale for following these phases is as follows. Scripts are suited to providing rich story detail in a linear format, but cannot easily represent a nonlinear or interactive story [20]. Graph representations can better show nonlinearity, interactivity, high level structure, and spatial relationships in a narrative [21]. Therefore, we expected graphs to ease the translation of a script to AR using Story CreatAR. The author-driven phase explores differences between how authors use Story CreatAR to translate their story using their graph or script. While many authors will use both a script and a graph (or flow-chart, decision matrix, etc.) when authoring interactive narratives, considering each in isolation allows us to closely consider the strengths and weaknesses of each when authoring and deploying immersive locative AR narratives. The developer-driven phase explores how a person with expertise in the spatial analysis techniques employed by Story CreatAR and the technical aspects of content production in AR/VR would use Story CreatAR to interpret an author's work using their script or story graph. We include this phase to model a content production workflow that would involve collaborators with different expertise. This allows us to compare the output generated by authors on their own vs. as part of a team, which helps us consider how the tool might support different workflows.

In this study we ask the following questions:

– What spatial attributes do authors represent using a graph or script that they are unable to apply in Story CreatAR? What are authors missing in their script or graph that would be required for a locative AR story?
– What spatial rules do authors use in Story CreatAR, how often do they use them, and do their rules achieve their desired effects?

2 Background

2.1 Spatial Analysis

In this section we summarize quantitative spatial analysis techniques used in Story CreatAR. Other important attributes of a space (lighting, materials, uses of space, etc.) not directly managed by Story CreatAR are not covered here.

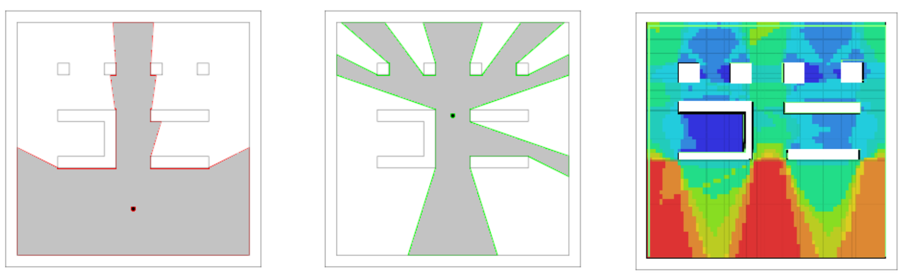

Fig. 1. Left: a point with high openness (high isovist area relative to other points). Middle: a point with high visual complexity (we see a "spiky" isovist, such that the point is visible from many vantage points). Right: visual integration of all points in the building (in aggregate): red shows most connectivity and blue shows least. Note that the alcove area with low visual integration also has low openness and low visual complexity.

Space Syntax Space syntax [5, 22] is a family of spatial analysis techniques typically applied to urban spaces and buildings–to understand how an area's spatial characteristics influence movement patterns, how spaces are used, and the visibility and accessibility of resources in the space. We present a brief overview here; further details can be found elsewhere [23]. Story CreatAR uses depthMapX [24] and AFPlan [25] to perform space syntax analyses on a floorplan. DepthMapX performs *isovist analysis*, a subset of space syntax analysis involving *isovists*. An isovist may be understood as the space illuminated by shining a flashlight 360 degrees around a point. Story CreatAR uses three characteristics derived from an isovist, shown in Figure 1. *Openness* [4] is the magnitude of the visible area about a point. *Visual complexity* is calculated using the perimeter of the isovist and [4] is a measure of how much you can see from one location. *Visual integration* is an isovist-based measure of the connectedness of a point, in terms of the average number of isovist intersections needed to "reach" the point from any other point: by viewing visual integration values for all points in a space simultaneously, we get an approximation of how "central" different regions are relative to the space as a whole (see Figure 1). These attributes can be combined: for example, high visual complexity and low openness denote a "spiky" isovist, a point visible from disconnected vantage points throughout the space. Story CreatAR uses AFPlan to conduct *convex analysis*, a subset of space syntax analysis which identifies convex regions (e.g., rooms), their dimensions, and their entrance points. Convex analysis generates a convex map, which contains the minimum amount of *convex spaces* to cover the entire environment. A *convex space* refers to an enclosed region where any two points within the region can see each other. Convex analysis allows Story CreatAR to support rules that constrain placement of multiple story elements to the same room or adjoining rooms, for example. Authors may choose to select one or more floorplans provided by Story CreatAR, or they may upload their own. After conducting space syntax analysis on the floorplan(s) Story CreatAR uses them to demonstrate how author rules for content placement and story events could be manifested in each space.

F-formations F-formations [8] refer to how people arrange themselves to interact with each other in co-located spaces. Kendon et al. [26] describe when f-formations (e.g., L-shaped) occur. They have been used to support fluid interaction between people [27], and to simulate realistic behaviors for avatars in VR [28–30]. F-formations are used in Story CreatAR to arrange avatars in conversation.

Proxemics Proxemics [7, 31–36] is an area of study that describes the impact of relative distance and orientation on relationships between people and devices. Llobera et al. [37] suggest that a viewer's stimulation increases as the distance between themselves and objects in VR decreases. Story CreatAR uses the ProxemicUI tookit [36] to define proxemic (distance and orientation) triggers between the viewer and avatars in conversation. For example, coming within 3 feet of a conversation (proxemic distance trigger) might cause the avatars in the conversation to turn toward the viewer, address them, and adapt the f-formation to include them.

2.2 Locative Media Tools

Locative media has been explored extensively in human-computer interaction (HCI) and new media research [16, 38–42]. While some platforms supporting the creation of locative media have been presented in the literature [43, 21, 44] or made available by practitioners [45, 46], we still know relatively little about how to best support such narratives [47, 19]. For example, tools often lack support

	StoryPlaces	Mscape	Hargood et al.	Story CreatAR
Easy Remapping	✓	✓	✓	✓
Separation of Logic	✓	✓	✓	✓
Extensible Rules		✓		✓
Use of Spatial Analysis			✓	✓

Table 1. Comparing locative media tools to Story CreatAR.

for managing unpredictable user movement and understanding the impact of the setting [48].

In Table 1 we compare Story CreatAR to locative narrative tools in the literature, specifically StoryPlaces [21], Mscape [44], and a location-adaptive system proposed by Hargood et al. [49].

StoryPlaces [21] is a generic web-based authoring system for locative narratives. StoryPlaces uses *sculptural hypertext*: every node is linked by default and these links are filtered out by conditions (logical, locative, and time-based). StoryCreatAR supports locative narrative creation with the same kinds of conditions. StoryPlaces is designed specifically for outdoor experiences, has limited support for using the viewer's proximity and orientation for story progression, and anticipates a web-based interface on a handheld device.

Hargood et al. [49] propose an approach for a rule-based system that uses generic space types (e.g., road, park, noisy) to dynamically map locative narratives to different environments. They envision site-adaptive locative tools that separate the narrative structure and the locative design, find local candidate locations that match requirements set by the authors, and then map story content to suitable locations. Story CreatAR realizes some aspects of this proposal, specifically using author-specified spatial rules to map story elements to suitable locations in an environment.

Mscape [44] is a site-specific authoring tool that provides an interface for non-technical users with extensible rules, the ability to specify events and conditions, to represent user knowledge, to use different media, and to iteratively test rules using a visual representation of the story on site. Story CreatAR provides similar features applied to site-adaptive, immersive AR.

Guidelines for Authoring Locative Media Longford [16] identifies key design considerations when considering environments: how someone feels in the space, the impact of time, the rules/policies of the space, and the presence of others. According to Packer et al. [19] authors must balance deal breakers (e.g., effort to reach location) and aesthetics (e.g., mapping narrative components to the environment), and make pragmatic decisions (e.g., bottlenecks may force passage). Nisi et al. [50] recommend visual markers to compensate for tracking inaccuracies and enhance understanding, and note that physical features (e.g., walls) can have more influence on user decisions than digital features. Bala et al. [51] find that lighting and audio are effective in directing attention in immersive (VR) stories. Azuma [17] considers three approaches for locative AR experiences: augmentations to improve an interesting environment, re-purpose an environment to fit your story, or retell the stories of an environment.

Many see VR/AR as heirs to or interlocutors with cinema [52–54]. Since cinema considers viewer position and perspective, and content positioning to be important within a setting, AR inherits that importance. Barba [14] defined five scales based on physical movements and interactions within a space that roughly correspond to cuts in cinema: figural, vista, panoramic, environmental and global.

Benford et al. [12] note that maintaining a coherent continuous trajectory for the viewer can be most challenging at key story transitions, or when shifting between a virtual and physical focus. Struck [11] and Dooley [10] also find viewers need time to situate themselves and acclimatize to new spaces as they move through a story.

While there are guidelines and tools in the literature for locative narrative and AR content independently, few consider immersive locative AR narratives specifically, and we lack authoring tool support focusing on viewer perspective, position, and trajectory in relation to the structure of space and events tied to that space.

2.3 Spatial Analysis and AR/VR

The spatial characteristics of buildings and rooms impact a player's experience and satisfaction in mixed reality [55]. For example, in a study by Shin et al. [56] players in AR experienced higher presence and engagement in larger rooms. Seung-Kwan Choi et al. [57] show that mutual visibility–an isovist-based spatial attribute–can be used to place important objects for game levels in optimal locations. Adventure AR and ScavengAR [58] are examples of building-scale AR games that place game elements using space syntax attributes. Recent work [59–63] has considered techniques for adapting AR/VR content dynamically based on spatial properties. While these works show promise of using spatial analysis for content and event placement in AR/VR, they do not consider how to support authors in doing so themselves.

3 Story CreatAR Workflow and Features

This is the first evaluation of Story CreatAR from the author's perspective. Story CreatAR is described in detail elsewhere [1]: here we focus on the authoring workflow and details that are most relevant to our findings.

3.1 Workflow

The Story CreatAR workflow is represented in Figure 2 and described as follows.

1. An author creates a draft of their story outside Story CreatAR.

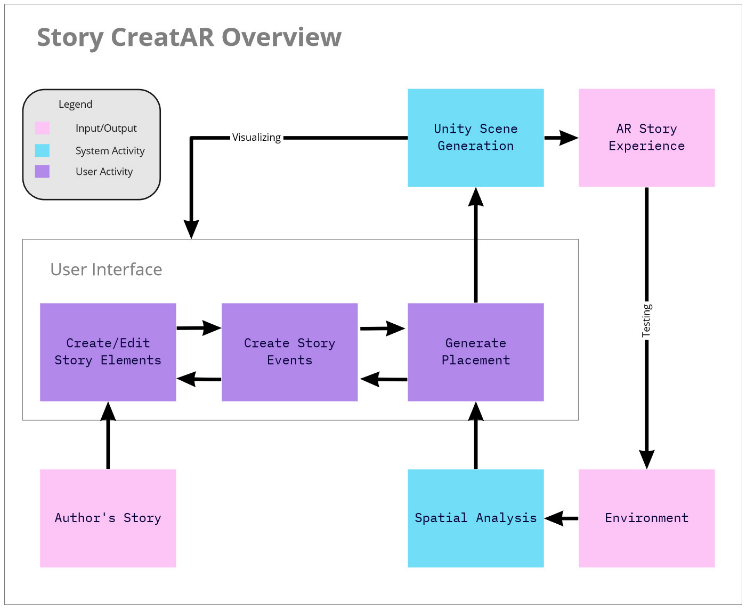

Fig. 2. Overview of the Story CreatAR workflow.

2. Using the Story CreatAR interface through Unity [64], an author adds and edits story elements (avatars, 3D sounds including character audio and narration, objects) and creates story events (conversations, avatar traversals, timer-based events).
3. The author specifies spatial rules for placing story elements, which can be tested by generating placement based on one or more floorplans.
4. If satisfied or curious with the placement, the author can generate a Unity scene, which provides a rich 3D preview.
5. The author can adjust story content in Story CreatAR or make manual changes to the scene before deploying the story.
6. The author can test the deployed story remotely in VR or on-site in AR.
7. This process can be repeated until the author is satisfied with their final output.

3.2 Features

Story Content Authors are provided with life-like avatars from the *Rocketbox Avatars* [65], spatialized sounds, and 3D objects to compose their narrative. These can be grouped for organization or to apply rules to all group members, where one story element can be part of 0-to-many groups.

Event Mechanics Using the interface, authors can create *conversation nodes* by specifying the type of conversation (intimate, personal, social), formation (e.g., avatars form a circle), and avatars that may be present. Authors can also specify two types of dialogue: avatars talking to each other or to the player. Conversations can be triggered based on player proximity, elapsed time, or completion of another event.

Story CreatAR also supports avatar traversal and timer events. Timer events can be used to add timestamps for other story events. Traversal events describe where an avatar can move. Both events have preconditions, which start the event only after other event(s) have started/completed.

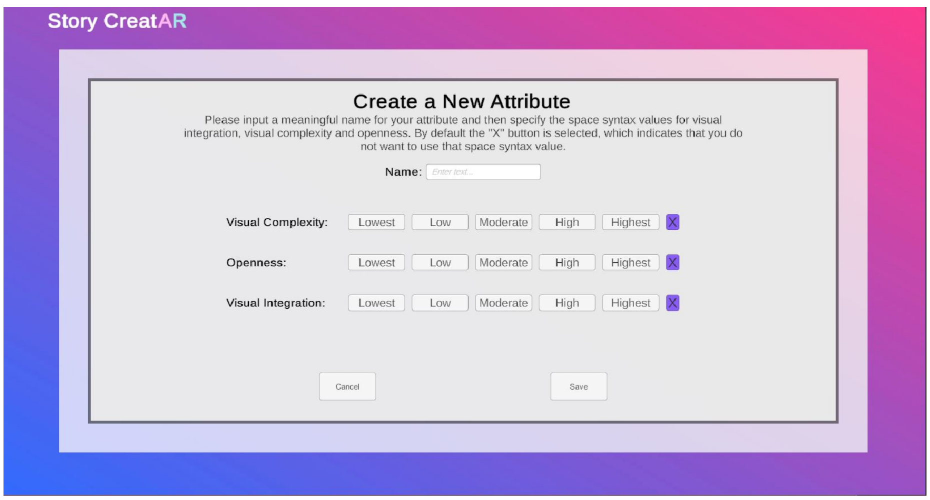

Fig. 3. Authors can create a new attribute in Story CreatAR

Placement Rules Authors specify spatial rules known as *attributes* to map story elements to different locations. *Rooms* are one type of attribute created by specifying a unique name and size (small, medium, or large). The other type of attribute uses isovist-based space syntax properties: openness, visual complexity, and visual integration. Story CreatAR combines these into several more understandable 'high-level attributes', each consisting of a meaningful name, and ranges of each space syntax property, with the option for authors to create their own, as shown in Figure 3. Based on the attributes and their priorities, an example placement of story elements is displayed, as seen in Figure 4.

4 Methodology

4.1 Population

In our study we work closely with three authors as story creators and users of Story CreatAR; we use pseudonyms in this paper. *Ryan* is a cinema and media

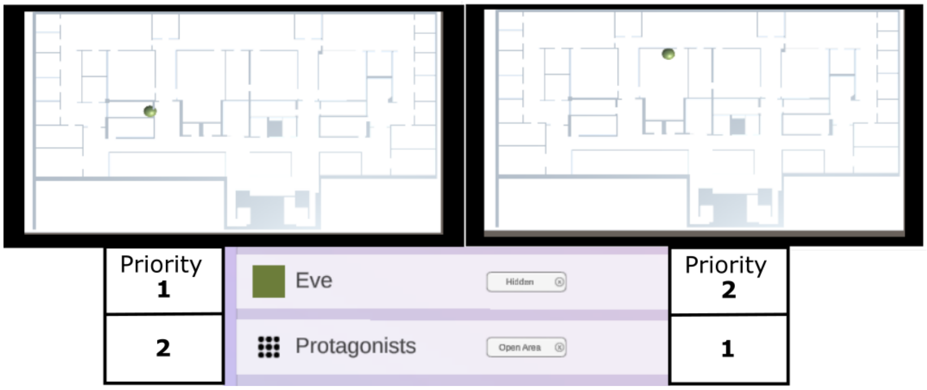

Fig. 4. Left: Eve placed with "Hidden" as highest priority. Right: Eve placed with "Open Area" as highest priority.

studies graduate, and our most technical author with his interest in video games and year of computer science study, which inspired his story *Spill*. *Eric* is a cinema and media studies student with experience writing children's books, but limited technical experience. He created a story called *Standville Museum*. *Anna* is a cinema and media studies graduate who won several creative writing prizes and wrote the story *Tyson's Peak*. Due to other commitments, Anna's supervisor *Amy* (a professor in cinema and media studies) acted as the author for Tyson's Peak in our study.

4.2 Study Design

Research Phase	Summary	Sequence	Duration
Script Creation	Author creates story script	Related topics (e.g., spatial analysis concepts) were introduced, Story CreatAR features were demoed, and feasibility of story ideas were discussed	16 sessions over 4 months
Graph Creation	Author uses part of story script to create graph in Miro (graphing tool)	Explain Miro features, show developer example, author creates graph, interview questions, and author adjusts graph	6-7 sessions per author (avg. 50 min. each)
Author using Story CreatAR	Author implements story in Story CreatAR using graph and script	Overview of Story CreatAR features, author implements story, and interview questions	4 sessions per author (avg. 1 hour each)

Table 2. Breakdown and summaries of the three creation phases

In this study, three film studies students worked through different phases, summarized in Table 2. Ryan, Eric, and Amy provided informed consent to participate in the study. Due to COVID-19, sessions were recorded and held virtually through Microsoft Teams [66]. During the sessions authors were asked to "think aloud", and a facilitator would probe for more details as necessary. We concluded phases with a semi-structured interview where the author reflected on the phase.

Phase 1: Creating a Story Script We met with the authors weekly over four months as they wrote their story scripts. We introduced spatial analysis concepts, walked through Story CreatAR and its ongoing revisions, discussed related work in new media and HCI, discussed the feasibility of story ideas the authors had, and shared other stories implemented using Story CreatAR. More details of this process can be found in another paper [1].

These discussions influenced the stories. In *Spill* the player is at a tea-party, where interactions and eavesdropping with party-goers affect the course of the story. In *Standville Museum* the player visits a museum with his son, Max, when Max is kidnapped by a demonic figure. The player follows clues to recover his son, where his choices lead to vastly different endings. In *Tyson's Peak* the player must solve a murder mystery by eavesdropping on eight friends trapped in a snowed-in cabin.

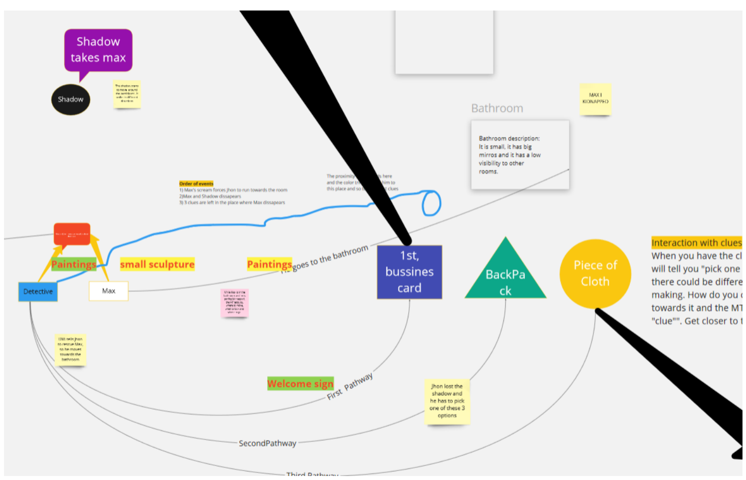

Fig. 5. A segment of the graph for Standville Museum created in the graph creation phase

Phase 2: Creating a Story Graph We introduced the Miro online whiteboard [67] tool and some of its features in the first session, and showed an example graph of “The Three Little Pigs” children’s story. In The Three Little Pigs example there was a story start and end node, story events as nodes, transitions between events as arrows, and frames as physical locations.

In the following sessions authors created a graph for a section of their story. We prompted the authors to consider how the graph can indicate aspects of the story that most directly translated to Story CreatAR features: how to represent positions, room descriptions, proximity triggers, formations of avatars, etc. A segment of Eric’s graph is shown in Figure 5.

Phase 3: Authors using Story CreatAR Interface After creating the graph, the authors used Story CreatAR directly to implement a part of their story in four one-hour sessions. In the first session, the developers showed assets acquired for their stories (e.g., tables, museum paintings, and others) and provided the author with a brief review of features in Story CreatAR. In the remaining sessions, the authors worked on implementing their story. The last session ended with a half-hour interview, during which authors discussed the pros and cons of using a script vs. using a graph to produce content and rules for Story CreatAR, and limitations of the tool.

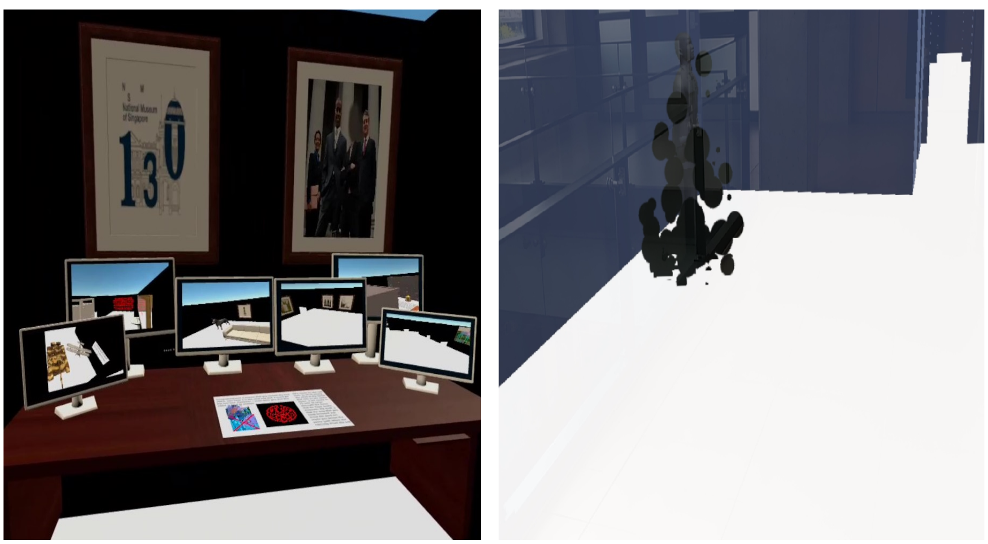

Fig. 6. Left: the implementation of Standville Museum in VR, showing the security room. Due to COVID-19, we tested our stories primarily in VR, but on-site AR is the target deployment medium. Right: part of the story rendered in AR. In this case virtual walls are rendered because AR could not be tested in the target deployment site, which was closed to all access.

4.3 Data Collection and Analysis

All sessions were video recorded, and artefacts from story creation (scripts, graphs in Miro, Story CreatAR logs and output) were retained.

Affinity Diagramming Sessions We conducted *deductive* thematic analysis similar to Braun and Clarke [68]. We began by familiarizing ourselves with the data, creating initial codes and improving the codes after looking at the data, and then we coded the videos. Our initial codes included *confusion*, *giving up*, *asking developer*, *making mistakes*, and *changing mind*. However, we added codes for *developer suggestion*, *technical confusion*, *author missing details from the graph*, *author suggestion*, *author likes something*, and *changing task without finishing current task*. Two researchers were assigned to code each video until the inter-rater reliability (IRR) was greater than 0.7, in which case the videos were divided between the researchers. We calculated the IRR based on coder agreement [69]: count of matching researcher codes (same code over similar times) over total unique codes. While coding for uncertainty, researchers also noted interesting observations. We also did an *inductive* thematic analysis similar to Braun and Clarke's procedure [68]: familiarizing all but one researcher with the data, noting aspects of the video we found interesting, and creating categories during an affinity diagram session on these annotations.

Six researchers created the affinity diagram. First, we moved the annotations for a subset of the sessions to Miro and divided them equally amongst the researchers. Then, we silently read and moved annotations to form groups. This step continued until we were no longer moving annotations. Then, we verbally settled any differences in opinion between the researchers and labelled annotation clusters as categories. From our initial 247 annotations, we created six categories and 36 sub-categories.

Next, one researcher added the annotations for the remaining videos. As the researcher added annotations, they created sub-categories, increasing the total sub-categories to 74 for 1087 unique annotations. Collaboratively, we reviewed these new categories/sub-categories during an hour-long session, and carefully considered certain categories individually. Some sub-categories were renamed and repositioned, and some were added. This resulted in seven top-level and 93 sub-categories. See Table 3 for a summary of the themes in the graph and interface approaches.

5 Results

5.1 Events

Timed Events Authors describe challenges with coordinating event timing and other events, as Amy demonstrates, "You don't know how big the space is, so you don't know how long it takes for the avatar to get to a room". It is less of an issue in film than AR due to the ability for cuts, which could explain why the authors seemed to lack timing details.

Theme	Summary	Code Coverage
Space and Placement	- Spatial analysis, position, and room considerations. - Spatial analysis learning curve experienced by authors.	23%
Graph Creation Process and Experience	- Authors process, use of graphing tool, and insights. - Authors creating graph from their script and missing story details.	20%
Events	- Authors use of formations, movement, and event triggers and preconditions. - Difficulty of determining event relationships	14%
Story CreatAR	- Authors experience with the user interface and the generated 3D Unity Scene	19%
Story Graphs	- Visual appearance of story elements in graph - Difficulty with story element representation	19%
Conversations	- Formation of avatars in conversation - Proxemic trigger of a conversation	5%

Table 3. Summary of affinity diagram themes for graph and interface approaches.

Triggers and Group Formations Authors were able to understand and use proxemic rules in Story CreatAR. However, Ryan and Eric had difficulty quantifying the proxemic distance. For example, Eric says, "I know how close it is, but I don't know how to explain it". Most references to orientation rules were focused on "looking at" story elements (at a player, object, or avatar).

While not supported in the interface, all authors described distance proxemic triggers between the player and rooms, the ability to use multiple triggers (using an "OR"), a trigger based on cardinal direction (North/East/South/West), and Amy wanted an always true trigger. There is also interest in interactions between the player and the walls/rooms/windows.

Authors used, understood, and liked group F-formations. While the circle formation in Story CreatAR was acceptable, authors desired other F-formations like ones that interact with the environment (e.g., props), semi-circles, or custom arrangements. Ryan and Amy chose the distance between avatars in a F-formation based on character relationships.

5.2 Space and Placement

Spatial Analysis Learning Curve The authors had difficulty understanding space syntax, which may be due to unexpected results of the higher-level attributes in the interface, the difference between the full complement of space syntax attributes and the ones available in the interface, or the unknown value of using space syntax attributes for stories.

Part of the difficulty for authors was that the space syntax characteristics used in Story CreatAR do not account for furniture. Amy's and Ryan's translation of openness, visual integration, and visual complexity based on the term alone is not entirely correct, but it still drove their use of the attribute. Amy reasoned, "Visual complexity may be thinking of metaphor: forest has high visual complexity and field has low visual complexity" and Ryan interprets openness as "assuming limited amount of things around it". Sometimes the author tried to understand extreme cases of the space syntax characteristic or the relationship between them. The understanding may also have been incorrectly built through singular testing of the placement in the interface. Interestingly, the high-level attributes, which were designed to provide more familiar, identifiable spatial properties (e.g., hidden region) were subject to the same misinterpretations as the low-level space syntax characteristics.

Rooms The authors describe rooms in terms of size categorically (small/ medium/ large) or precise measurements, relativity to other rooms or room features (doors/ windows), and visibility to other rooms. Amy experimented with rooms for different floorplans in Story CreatAR. There was evidence that thinking in terms of room attributes is not apparent for authors (e.g., Ryan felt room size was not necessary for storytelling).

The authors also consider the number of doors per room to connect spaces and windows due to light access. Ryan and Amy would specify the hallway as the largest room with the most doors, which could be a way of trying to squeeze specificity out of the tool. Ryan and Eric use doors as a reference point in their story. The authors also described general ways to specify room shape (e.g., long/thin, square/round, spikey/complex). In addition, the authors indicate different room properties would have different priorities.

Positioning Both Ryan and Amy show a translation from their story script to the default attributes. The use of space syntax had some unexpected use cases and challenges. Unanticipated uses of space syntax include defining where to play an off-screen voice, and having placement correlate to types of characters. For example, Ryan assigns attributes based on character personality (e.g., Bultilda is confident so she is in an open, easy to find area). It was challenging for authors to maintain flexible placement, as shown by authors desire to maneuver objects to appropriate locations manually. Eric felt nervous when adjusting placement rules: "I had like a mini heart attack". Amy iterated on creating a new attribute, reapplying rules, and making modifications based on the placement shown on the map.

We observed a tension between creating meaningful labels for story content and using the high-level attributes. Ryan created a new attribute in an unintended way: to create labels for story aspects not supported by the tool. His labels were used to indicate object containment relationships, interactive events unsupported by the event model logic, and desired placement not supported by space syntax attributes. For example, Ryan creates an attribute with no space syntax attributes called central doorway and shares, “so my hope is that'll [the attribute] just assign it to there [the story element], but I don't think it'll show it here [placement map]”.

6 Discussion

6.1 Spatial Analysis Insights

Authors had positive and negative experiences with the spatial rules. Amy appreciated the degree of “accident” caused by the use of automatic room selection. When switching between floorplans, she comments “Oh I like that much better. Perfect actually, I love that, so I like the way the system has just clustered them”. Eric commented that Story CreatAR could support story creation due to the flexibility in adding content, despite worrying about how to represent player self-conversations. Conversely, Ryan found the process more difficult than anticipated and doubted Story CreatAR's suitability for implementing highly interactive stories. In this section we discuss several key ways in which Story CreatAR can be improved: addressing the spatial analysis learning curve, helping authors consider multi-site deployments, and supporting more spatial relationships.

Need to Address Spatial Analysis Learning Curve The literature [56, 57, 59, 60, 58] shows several examples of tools designed and used by researchers that use spatial analysis techniques, but they do not support end-users in learning and effectively using those concepts. Moreover, other applications of on-the-fly spatial analysis [61–63] are not appropriate for locative AR due to continuity issues (e.g., an avatar directed to move to a room far from the player, but that content is not generated) involved in building-scale narratives.

In our evaluation, we find a need to help authors overcome the spatial analysis learning curve. Authors had difficulty understanding spatial attributes in the interface and were subject to misinterpreting their meaning. Even with relatively basic proxemic relationships, authors were subject to the same misinterpretations. We expected the small number of attributes available in Story CreatAR (openness, visual complexity, and visual integration) would be effectively used and combined once grasped. Instead, authors more often experimented with each attribute to see if they could achieve an effect they wanted, rather than deliberately choosing and combining attributes based on their comprehension of them. These results are in line with Raford [70], who interviews space syntax experts who warn that space syntax terminology without appropriate technical knowledge is difficult to understand and use.

There are a number of ways to improve space syntax comprehension: presenting different layouts simultaneously, clear descriptions and examples, immersive walkthroughs, and demonstration-based rule creation. Story CreatAR currently supports viewing attributes for story elements across multiple floorplans non-simultaneously, and our authors often did not switch between floorplans when testing their rules. It is also currently possible to deploy and test in VR, but the steps required should be minimized in the interface.

Ryan's and Eric's actions and comments suggest a programming by demonstration interface. When asked how manual manipulations of position on the map could be extended to involve the attributes, Ryan says, "it could actually make it easier to add the attributes because then when you click and drag and you place it [story element] somewhere, you can be like okay generally this is the kind of location I want it to be". When Eric created his graph, he placed objects where they would appear in physical space to demonstrate types of locations objects would be in and their relativity to one another. In this way, authors do not require specific knowledge of the spatial rules, but can instead specify rules based on visual inspection of the layout. Spatial analysis can still be used in the background to remap story content to appropriate locations.

Helping Authors Consider Multi-Site Deployments For locative narratives, it can be very useful if a tool allows an author to remap story content to multiple locations [21, 49], but it is challenging to write content that works in different sites [48]. The inability to specify precisely where story content goes in a site-agnostic experience results in a lack of control that can be challenging for authors.

There were numerous instances of authors indicating the desire for manual control or precise specifications concerning placement. Ryan suggests manual movements, "it would be nicer if you could see more obvious use of the mini-map (click and move objects on the 2D model even if it is a small grid)". Authors also desire specifying precise measurements for rooms. In addition, Eric was worried he would "destroy things" by pressing "reapply rules", which indicates they considered the precise object placements and not the generic rules the sample placement on the visible floorplan was one manifestation of. Amy indicates that thinking of placement flexibly does not come naturally to authors, "If I were just writing a screenplay for fun, that was never gonna be passed on to anyone I actually would design the space, like I would map it. However, with Story CreatAR in mind and that amazing flexibility that it has to be adapted to different spaces, I wouldn't [do manual placement]".

Showing multiple floorplans simultaneously may help authors to consider spatial rules more abstractly. Authors may also want to specify general features likely to be available in a building (e.g., front entrance, stairs) or features specific to the space where the story is meant to be experienced (e.g., theatre stage, balcony, vestibule). Not having any information about how a space is used can produce a negative result. For example, Amy liked the placement of objects in a room that she did not know was a bathroom. In future, Story CreatAR may expose ways for authors or site administrators to exclude certain rooms.

Additional Spatial Analysis Support The space syntax attributes currently provided in Story CreatAR cannot manifest some of the desired spatial constraints we found in the graphs, scripts, and/or suggestions made while using

Story CreatAR. More work is required to determine a parsimonious set of space syntax attributes to make available for use when creating spatial rules. For example, the isovist property of minimum radial length might be useful for placing objects along walls, and isovist intersections can be used to determine mutual visibility [71].

In addition to isovist-based attributes, Story CreatAR should support more convex-based properties. Story CreatAR already uses AFPlan to conduct automatic convex analysis to identify corners of rooms, which can be used to compare relative room size and detect whether a player/NPC/object is inside/outside or entering/leaving a room. A justified connectivity graph could be generated using convex analysis, representing how many rooms need to be traversed to move between two points, as a room-level complement to the visual integration attribute, giving measure of proximity between rooms, and establishing a room's overall accessibility. Agent-based spatial analysis can be added to identify areas of predicted low/high traffic, an attribute our authors suggested. Room dimensions and accessibility can be helpful in determining event timings that involve avatar or viewer movement through spaces. Currently, Story CreatAR uses ProxemicUI for basic relative position and orientation between two entities and circular f-formation placements, but the toolkit allows more varied and complex proxemics relationships and formations to be specified. The "entities" available for use in these rules could be expanded to include room elements (e.g. a doorway) and story objects (e.g. a painting).

Providing attributes like those mentioned provides expressiveness approaching what the authors indicated in their materials and comments. For example, a hallway could be a room with high centrality (determined using the connectivity graph), a rectangular shape, and several doorways (using convex analysis). A rule could place an avatar at one end of the hallway, and it could interact differently as a viewer approaches. Finally, the mechanics of combining and prioritizing spatial rules should also be clear to authors using the tool, as should the impact this will have on the resulting story configurations.

6.2 Limitations

We investigated with only three authors, allowing us to focus on rich narratives over a long period of time, but also has certain limitations. The small sample size may have certain implications on our results: high variability, low reliability, and skewed representation of potential users.Our authors were influenced by our research focus–on the use and effects of spatial rules for immersive AR narratives–while writing their stories and moving through the authoring phases. Consequently, authors potentially considered rules relating to spatial attributes (e.g., openness, traffic), inter-room relationships, and intra-room relationships precisely because these were discussed with them, even though they were not always available in Story CreatAR. Furthermore, authors were in contact with Story CreatAR designers throughout these phases. We expect that users using Story CreatAR or a similar tool would not have access to this level of support. Additionally, since our authors did not use Story CreatAR over a long period of time, it would be interesting to see how an author's experience changes over time. Would authors still remember decisions they made or would they want to change previous decisions? For example, an author may have previously created an attribute with a specific name and associated space syntax values, but does the author still find this meaningful to use for their story? Finally, while this in-depth qualitative study provided rich data on supporting spatial thinking when authoring immersive AR narratives, studying additional authors with different story ideas would help to establish common graphing approaches, spatial rules, and interface preferences.

7 Conclusion

In this paper, we investigated how three authors of locative AR narratives use spatial rules and how effective those rules are while using Story CreatAR, a tool that allows authors to specify placement rules that are used for remapping story content to different locations. Authors worked in distinct phases: creating a story script, creating a story graph, and using the Story CreatAR tool. We find authors experienced difficulty using the available spatial analysis techniques effectively, often misinterpreting the meaning of specific spatial rules and misunderstanding the sample placement of the rules. Authors also had difficulty thinking abstractly about relationships between their story elements and physical environments. Nonetheless, our authors defined complex spatial rules during story creation that were cross-checked and refined when using Story CreatAR, and they desired more sophisticated spatial analysis support in the tool. Our findings inform future directions for Story CreatAR, but are also valuable for any tool that wishes to make spatial analysis techniques comprehensible and actionable to creators like authors, game designers, and developers of other forms of locative experience. To help these content creators we recommend designing interfaces that promote comprehension of spatial properties as and where they are used, reinforce flexible notions of location and position by visually representing multiple deployment sites and/or multiple applications of a set of spatial rules to the same site, and provide rule composition support that allows authors to both apply basic rules and define more complex rules as needed.

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