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RESEARCH ARTICLE

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Enriching the GIScience research agenda: Fusing augmented reality and location-based social networks

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Abstract

Augmented reality (AR) overlays real-world views or scenes with virtual, computer-generated objects that appear to visually coexist in the same space. Location-based social networks (LBSNs) are platforms for individuals to be connected through the interdependency derived from their physical locations and their location-tagged social media content. Current research and development in both areas focuses on integrating mobile-based AR and LBSNs. Several applications (e.g., Sekai Camera and Wallame) have been developed and commercialized successfully. However, little research has been done on the potential impacts and successful evaluation methods of AR-integrated LBSNs in the GIScience field. To close this gap, the article outlines the impacts and benefits of AR-integrated LBSNs and highlights the importance of LBSNs in GIScience research. Based on the status quo of AR-integrated LBSNs, this article discusses—from theoretical and application-oriented perspectives—how AR-integrated LBSNs could enrich the GIScience research agenda in three aspects: data conflation, platial GIS, and multimedia storytelling. The article concludes with guidelines on visualization, functionality, and ethics that aim to help users develop and evaluate AR-integrated LBSNs.

1 | INTRODUCTION

Augmented reality (AR) overlays real-world views or scenes with virtual, computer-generated objects that appear to visually coexist in the same space. It is well established in multiple domains and has achieved consumer market status, mainly due to the prevalence of smartphones equipped with high computational processors, high-resolution displays, and multiple sensors. As a result, AR is integrated into everyday applications, including games, marketing strategies, navigation aids, home design software, personal assistance and general education applications. However, one important aspect has not been discussed sufficiently: the potential application of AR in location-based social networks (LBSNs). LBSN discussions started early in 2010 when developers tried to better understand how to connect user locations with user social networks. LBSNs are tightly coupled with location information acquired from multiple sources, including GPS sensors embedded in smartphones, place information expressed by users' posted messages or pictures, estimated distance to cell towers, and so on. Such location information adds a layer of spatial reality to people's online social networks. As a result, LBSNs enable us to be more informed of people's behavior in society, and even predict spatiotemporal patterns of social events.

Inspired by the increasing importance of AR and LBSNs, the idea of combining them is not entirely new. Under the term "Augmented Reality 2.0" (Schmalstieg, Langlotz, & Billinghurst, 2011), there have been theoretical and technical approaches to integrating mobile-based AR and LBSNs. Several commercial applications (e.g., Sekai Camera and Wallame) have been developed successfully for the mass market. However, there have been few discussions on the potential impacts as well as evaluation methods of AR-integrated LBSNs in the GIScience community. To bridge this gap, this article discusses the impacts of AR-integrated LBSNs with a particular focus on how AR may benefit LBSN researchers in the GIScience field.

2 | LBSNS IN GISCIENCE RESEARCH

In recent years, LBSNs as an important data source have gained much attention from the GIScience community, due to their wide coverage of population and convenience of data acquisition. LBSN research goes beyond connecting a location to an existing social network. It not only considers sharing location-embedded information, but also assesses how individuals might be connected through the interdependency derived from their physical locations and their location-tagged media content (i.e., videos, photos, or texts). While two social media users might not be directly connected through social media links, their locations and common interests, behaviors, and other activities might indicate similar patterns. Smartphones provide several location-tracking options (GPS, cell tower positioning, WiFi localization, etc.) that enable mobile social media platforms. From Facebook, to Google, to Foursquare, recording physical locations has become crucial in social media usage. Thus, LBSNs provide large geoinformation databases that scientists can use to analyze various mobility issues, societal perceptions or opinions, and online behavioral patterns.

Aside from being valuable data sources, LBSNs also serve as testing fields for new conceptual models and frameworks regarding the interaction between humans and space. For example, Farman (2013) analyzed LBSN platforms as "interfaces of remembering," or means to create and disseminate embodied individual and community histories of place. He contends that, as people can access digital space anywhere using mobile devices, they then locate themselves in digital space and material space simultaneously, with each shaping perceptions of the other. Schwartz and Halegoua (2015) introduce the concept of the "spatial self," encapsulating the process of online self-presentation based on the display of offline physical activities. They argue that instead of simply occupying and utilizing physical space, people actually build their online identity by associating themselves with the narratives of a place, particularly with LBSNs.

Significant LBSN contributions in the GIScience field are summarized by Roick and Heuser (2013). In their assessment, LBSNs have played an important research role in:

1. analyzing and predicting social ties (Crandall et al., 2010);
2. assessing human behavior in space and time (Cheng, Caverlee, Lee, & Sui, 2011);
3. locating generated content (Gelernter & Mushegian, 2011);
4. locating users (Davis, Pappa, de Oliveira, & de L Arcanjo, 2011);
5. disaster response (Li & Rao, 2010); and
6. monitoring diseases and health (Collier, Son, & Nguyen, 2011).

In addition, other GIScience-based researchers state that LBSNs have been used in data quality assessments (Hochmair & Zielstra, 2012) and privacy protection (Vicente, Freni, Bettini, & Jensen, 2011). Both of these topics are major concerns, not only in LBSNs. In spite of all the useful applications of LBSNs, Roick and Heuser (2013) note that there is a lack of discussion on multiple critical LBSN issues, such as the representativeness and availability of LBSN data as well as debates on data ownership. For GIScience, we have observed LBSNs as being valuable resources from which novel research questions are raised and massive amounts of data are collected.

3 | THE FUSION OF AR AND LBSNS

3.1 | AR 2.0

AR is a technology that is utilized in several fields (i.e., gaming, education, and professional assistance) in multiple forms. AR-integrated LBSNs are best described by the term "Augmented Reality 2.0" (Schmalstieg et al., 2011), which envisions platforms that support the spontaneous authoring, storing, and sharing of AR content in place for a wide range of users. Similar to Web 2.0, the concept of AR 2.0 opens the door to crowdsourced AR information by shifting the authority over AR content creation and dissemination from enterprises and governments to the general public.

As argued by Schmalstieg et al. (2011), the implementation of AR 2.0 is facilitated by several key components, including:

1. smartphones as a low-cost platform that combine AR display, tracking, and processing;
2. mobility to realize AR in a world model;
3. backend infrastructure for the distribution of AR content and applications;
4. easy-to-use authoring tools for creating AR content; and
5. large-scale AR tracing solutions which work in real time (Schmalstieg et al., 2011).

These components need to be integrated into architectures which design the ways to construct AR applications on mobile devices. One representative architecture is the "Gateway" architecture (Butchart, 2011a) that describes the design framework of popular mobile AR browsers (Figure 1).

In the "Gateway" architecture, the "Platform" is a vendor-provided web server which mediates requests from the AR browser to the world model that is a digital representation of the environment, including points of interest (e.g., tourist attractions), 3D objects, and metadata (Butchart, 2011a). This design is named "Gateway" architecture since the "Platform" functions as a gatekeeper to virtual models published on the World Wide Web (e.g., Layar, Sekai Camera, and Wallame). For a more open AR browser architecture which enables the sharing of crowdsourced information, a "Web" architecture was proposed (Butchart, 2011a) (Figure 2).

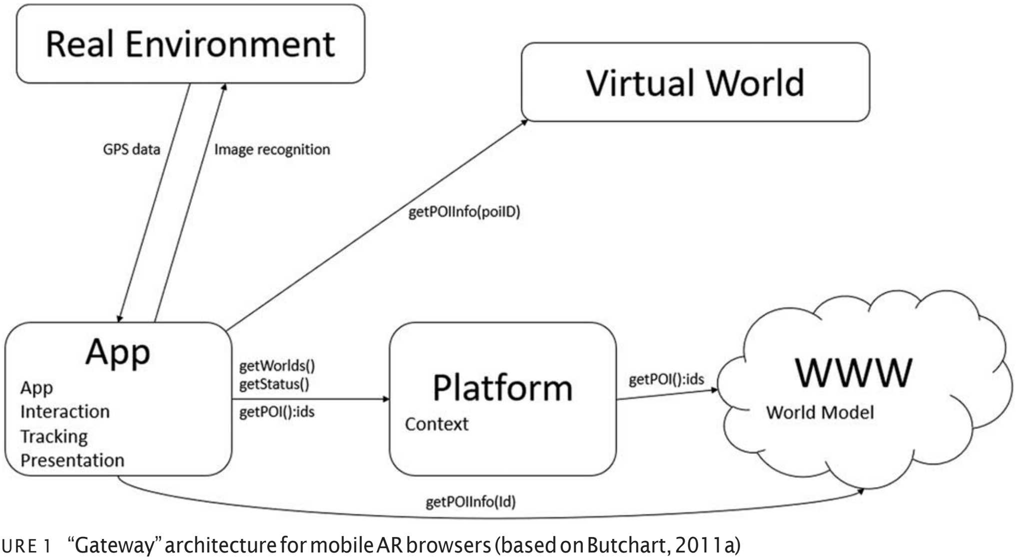

FIGURE 1 "Gateway" architecture for mobile AR browsers (based on Butchart, 2011a)

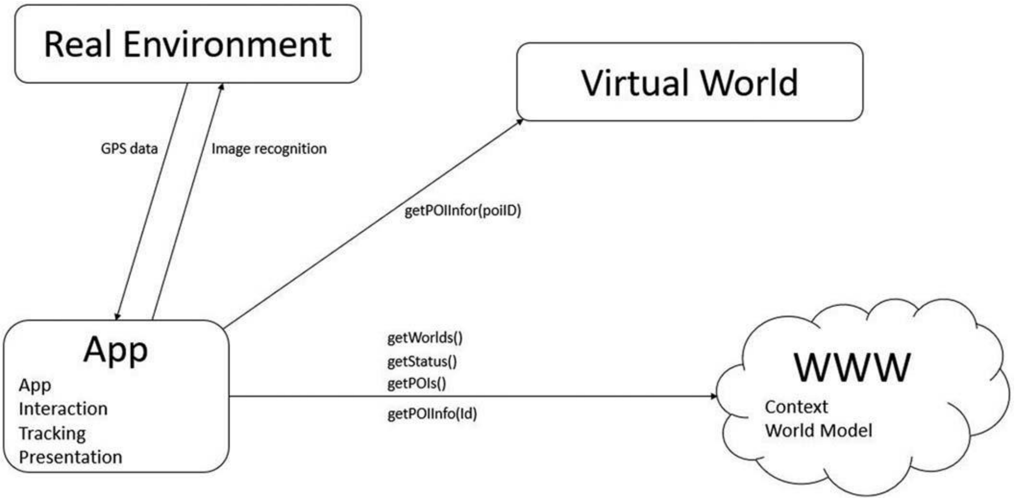

FIGURE 2 "Web" architecture for mobile AR browsers (based on Butchart, 2011a)

In the "Web" architecture, the "Platform" component is eliminated and the AR application becomes a genuine web browser with unmediated access to the World Wide Web (e.g., LibreGeoSocial). AR 2.0 can be implemented via both the "Gateway" architecture and the "Platform" architecture. The former is more restrictive for users, but offers vendors more control over content, which means better control over the quality of AR content but less freedom of creation. The latter releases users from any dependency on a platform provider, but requires them to make a good effort to make content discoverable and accessible through the world model (Butchart, 2011a).

3.2 | Existing applications

The fast development of smartphones with their integrated sensors (i.e., GPS, camera, gyroscope, accelerometer, magnetometer, etc.) resulted in several approaches to integrate AR browsers. Butchart (2011b) highlights five AR browsers that were developed for mobile devices: Layar, Junaio, Wikitude World, Sekai Camera, and LibreGeoSocial. Among these AR browsers, Junaio, Sekai Camera, and LibreGeoSocial supported social networking functionalities; however, Sekai Camera was the only commercialized development (exclusively for the Japanese market, but discontinued in 2013). Sekai Camera employed location-based tracking and offered developers and content publishers an application programming interface (API). This mobile application allowed users to create AR-based text messages, photos, and audio recordings (dubbed air tags) and "drop" them on the spot in the form of floating bubbles and icons. Other local App users were alerted about the posts and were able to interact with these geotagged virtual Post-It notes. Figure 3 shows the user interface of Sekai Camera.

For positioning purposes, only Junaio utilized computer vision (CV) for optical detection and recognition of markers and objects. The other AR browsers used GPS coordinates, the gyroscope, the magnetometer, and WiFi to position the smartphone. Therefore, it was difficult to accurately position user comments with particular objects in smaller spaces. In addition, the lack of CV techniques resulted in relatively static displays of information. For instance, a large music festival might draw the attendance of thousands of Sekai Camera users who would create thousands of AR-based "air tags." These "air tags" would remain visible in the social networks even if the event was over, unless the initiator removed them. Meaningless and outdated "air tags," combined with an unstructured information overflow, contributed to the termination of the Sekai Camera in 2013. In addition, the development of other mobile-based AR browsers that support social media network functions gradually halted over time.

FIGURE 3 User interface of Sekai Camera (Tonchidot, 2010)

Although the initial attempts to commercialize AR-integrated LBSNs did not succeed, the potential of mobile AR applications has been proven. In 2015, the Wallame App was launched on both iOS and android platforms. Wallame is very similar to Sekai Camera in that it enables users to post virtual messages or pictures in the physical world and share them with others. Depending on author preferences, messages can be shown to selected friends or any Wallame user (Figure 4). The adoption of CV techniques made positioning of messages in Wallame more accurate compared with Sekai Camera. In addition, messages in Wallame can be viewed remotely in a built-in picture gallery, so that users are not required to be physically present at the location where the message was created. Wallame has become a mature AR-integrated LBSN over the last three years, and claimed over 50,000 downloads on Google Play Store. However, Wallame currently does not support sharing 3D models, nor does it give users the opportunity to collaborate with each other on the creation and modification of AR content.

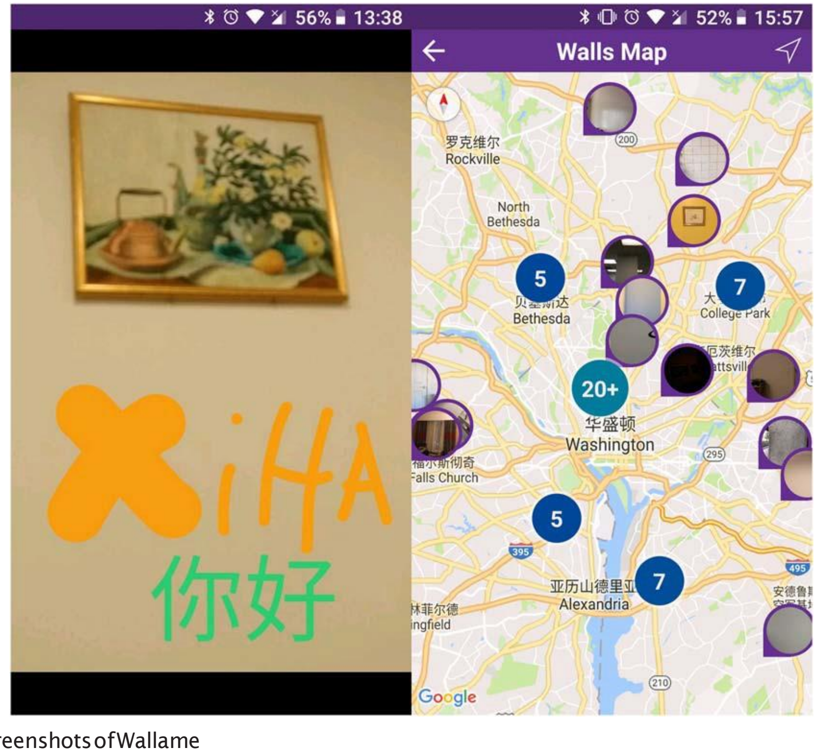

FIGURE 4 Screenshots of Wallame

3.3 | Enriching the GIScience research agenda

Over the last few years, AR-integrated LBSNs have demonstrated their potential as an innovative technology. In 2017, social network companies (e.g., Apple, Google, and Facebook) decided to invest in AR by launching their own platforms (i.e., ARkit, ARcore, and AR Studio). For consumers, AR-integrated LBSNs could provide new experiences in socializing and entertainment. As many of the functions and tasks relate to GIScience theory, GIScientists should participate in the fusion of AR and LBSNs. Thus, this process will enrich the GIScience research agenda. LBSNs have been explored and analyzed extensively in various GIScience-related fields, such as location inference, spatial dynamics of human behavior, event detection and prediction, spatial information extraction, and so on. However, as highlighted by Sui and Goodchild (2011), the convergence of GIScience and LBSNs brings key challenges to researchers in many aspects as well. Roick and Heuser (2013) summarized these challenges in three categories: new theories for GIScience, social aspects, and information extraction. They further address several open issues under these categories, which need a more thorough discussion in the GIScience community: data conflation, platial GIS, and multimedia storytelling.

3.3.1 | Data conflation

Data from LBSNs will attain their full potential when single data sets complement each other (Roick & Heuser, 2013). Otherwise, there will be much noise and misalignment in the data, which significantly mitigates its usability. Data conflation is necessary to process the massive amount of social media data from various sources with various levels of uncertainty (Sui & Goodchild, 2011). The problem of spatial data matching and conflation has been studied extensively throughout recent years. A number of methods have been developed, implemented, and evaluated, yet very few of these are implemented in the context of LBSN data, which is often vague in expression and poor in accuracy (Ruiz, Ariza, Ureña, & Blázquez, 2011).

Janowicz, Raubal, and Kuhn (2011) contended that in order to fuse geographic data from social networks, matching methods are required that employ geometric proximity and semantic distances in a combined manner. In addition, AR-integrated LBSNs can offer a third layer of ambient information to assist geographic data conflation at the local scale using CV techniques. For instance, principal component analysis is one of the most widely adopted CV techniques to identify features in an image (Ke & Sukthankar, 2004; Rodarmel & Shan, 2002; Swiniarski & Skowron, 2003). As an example for GIScience applications, Kawaji, Hatada, Yamasaki, and Aizawa (2010) combined robust image matching by PCA-SIFT and a fast nearest-neighbor search algorithm based on locality sensitive hashing (LSH) for indoor positioning. Their system quickly estimates user positions with high accuracy. Illustrated by Wallame, AR-integrated LBSNs nowadays rely heavily on CV to capture and analyze the surrounding environment in order to spatially register users' information in 2D or 3D space. In a popular place, people may create several AR messages that share the same environment information, from which common patterns or features can be extracted as a unique representation of the place. Such information can be utilized as a useful and accurate complement to geometric proximity and semantic distances in terms of data synthesis.

3.3.2 | Platial GIS

The concept of space has long been the primary way to associate information with a location on Earth. Space emphasizes accurate positions and distances, which can be measured and represented using geographic coordinate systems. However, humans tend to refer to specific locations by name, without knowing their exact position or extent (Elwood, Goodchild, & Sui, 2013). For example, the terms "Downtown Washington D.C." or "the hipster neighborhood in the city" refer to places without specific spatial boundaries, yet most people quickly grasp the essential characteristics linked to these vaguely defined concepts. Goodchild (2015) states that platial GIS is particularly important to understand human perceptions and behaviors in the environment and within society. Due to the uncertain and qualitative nature of places, platial GIS has not been fully explored before the prevalence of LBSNs. Goodchild and Hill (2008) described the gazetteer, an index of officially recognized place names, as providing an essential link between the informal world of human discourse and the formal, spatial world of GIS. Nevertheless, a gazetteer provides only a limited link, being traditionally composed of a triple (name, type, location), where location provides a point coordinate even for a spatially extended object (Elwood et al., 2013).

Platial GIS studies have been advanced significantly by user-generated content (UGC) acquired from LBSNs through large user groups. Citizens are more engaged in the production of place-based information (Roche, 2016). Personal places are being self-staged using people's words and perceptions. Hollenstein and Purves (2010) noticed that users seek to ascribe appropriate semantics to images. Therefore, they used 8 million Flickr images with georeferenced and tagged metadata not only to describe the use of the term "Downtown" across the USA, but also to explore the borders of city center neighborhoods. The study demonstrated the important notion of blurriness in platial GIS using UGC. As place boundaries were summarized from millions of geotagged pictures, taken by users with different boundary perceptions, region delineation was smoothed rather than outlined using sharp boundaries (Hollenstein & Purves, 2010). Cranshaw, Schwartz, Hong, and Sadeh (2012) developed a clustering algorithm for millions of users' Foursquare check-in data to find "livehoods" in cities. According to the authors, these "livehoods" have somewhat replaced the traditional idea of neighborhoods or districts, as they represent a more organic, accurate, and human-friendly city zoning. Studies like these demonstrate the importance and potential of UGC for the derivation of place representations.

AR can help in advancing our understanding of place formulated by crowdsourced LBSN data. Thus, we propose a corresponding model between AR-based information and what is construed as place. Place is related to the qualitative description and naming of a specific location, rather than to the geometric characterization of space (Roche, 2016). In a broad sense, space can be considered as physical reality and place as a virtual, fluid, and vaguely defined perception which overlays the reality of space. This corresponding relationship is modeled in Figure 5.

In traditional LBSNs, the virtual information which formulates place is separated from physical reality (space). For example, people may vaguely describe a "fun place" in a city based on people's comments online without visualizing it spatially. In AR-integrated LBSNs, the virtual information formulating notions of place actually occupies space through the AR browser. In the example above, people can see each other's comments virtually overlaying the surrounding environment and get a direct sense of where and what a "fun place" is. Therefore, AR visualizes how places are formulated and described in space. Another issue with traditional LBSNs is the uncertainty of localness. For example, LBSN users can write about a place while being physically at another place, which may violate the localness assumption of

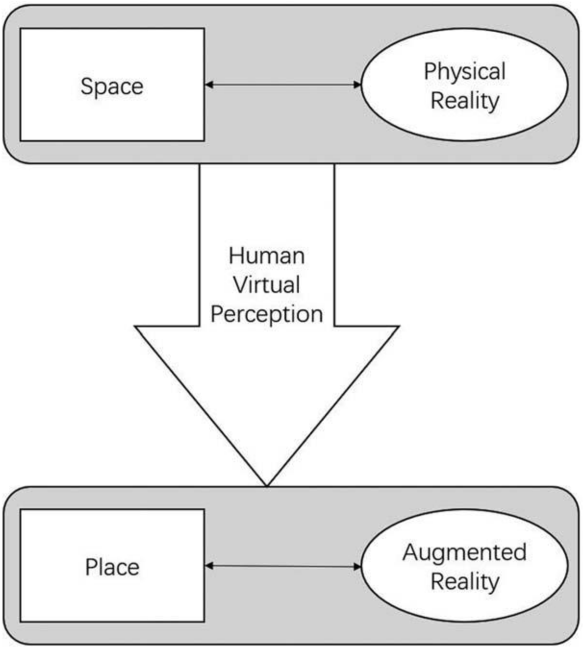

FIGURE 5 Correspondence between reality/virtuality and space/place

volunteered geographic information and generate inaccurate spatial data (Johnson, Sengupta, Schöning, & Hecht, 2016). With AR-integrated LBSNs, the impact would be mitigated as most people are encouraged to create content in situ.

AR-integrated LBSNs instigate a valuable GIScience research agenda regarding space and place interaction. For instance, users may have various perceptions regarding the same space, or share the same perception of different spaces. Such subjective inconsistency would hinder the discussion of important GIScience topics such as geospatial ontologies. Overall, AR-integrated LBSNs can display how users understand places differently and thus provide a more open and informed platform for communication.

3.3.3 | Multimedia storytelling

Geospatial technologies, open geodatabases, and web-based multimedia expand the ability and audience for storytelling through various kinds of spatial representations. Anyone with a smartphone or computer can use spatial representations to tell a story (Kerski, 2015). In response to this decentralizing trend of storytelling via spatial representations, Sui and Goodchild (2011) asked this now classic question, facing the convergence of GIScience and social media: Which methods and models can be used to link GIS with the "multimedia metaverse," to tell stories about the surface of the Earth better, and to develop a more coherent narrative for the future?

In recent years, several open platforms have been developed to use GIS and multimedia to tell stories online, such as Esri's Story Maps (http://storymaps.arcgis.com) and Map Story (http://mapstory.org). In these story maps, a user identifies a topic of interest, situates its spatiotemporal extent using timelines and maps, expresses his/her experiences or opinions regarding the topic, and enriches the story with supplementary media such as pictures, videos, and audio clips. Other users can interact with the story maps by exploring these places, viewing different timestamps, and adding comments. Storytelling usually occurs in a 2D web-based setting. AR-integrated LBSNs can generally enhance storytelling experiences because users are situated in the real environment. Zünd (2016) demonstrated that AR is a promising technology for storytelling, because it can enhance the immersiveness and interactivity of a narrative and create a social experience for multiple users.

With AR-based LBSNs, stories are not merely to be told but to be experienced in a holistic environment that embeds users, locations, objects, events, and emotions altogether. The user experience is transformed from relating different pieces of information to one another to "living through" the narrative (Bimber & Raskar, 2005). AR has a history of being used in professional fields for research and educational purposes (Bimber, Encarnação, & Schmalstieg, 2003; Braun, 2003; Feiner, MacIntyre, Höllerer, & Webster, 1997; Höllerer, Feiner, Terauchi, Rashid, & Hallaway, 1999). Recent efforts in the creation of "AR Portals" developed via ARkit, which allow users to physically cross a virtual portal in the AR browser and experience different spatiotemporal realities, have shown the potential for users to create, experience, and share content-rich stories in AR. A combination of AR, geoinformation, and social networks will create a highly interactive and personalized storytelling experience (Figure 6).

4 | ENRICHING THE GISCIENCE RESEARCH AGENDA: DEVELOPING AND EVALUATING AR-INTEGRATED LBSNS

With more consumer market and advanced AR technologies and applications on the horizon, the advancement of AR-integrated LBSNs is foreseeable. To better understand the characteristics of different AR-integrated LBSNs, and to improve their usability and usefulness, it is necessary to adopt development and evaluation guidelines that are systematic, valid, and consistent. Papagiannakis, Singh, Magnenat, and Thalmann (2008) compared 30 mobile AR browsers and developed five application criteria:

1. application domain (what does the AR browser do?);
2. location (is the AR browser used indoors or outdoors?);
3. type of display (is the AR browser handheld or head-mounted?);

FIGURE 6 Screenshots of an "AR Portal" prototype (Nedd, 2017)

4. content augmentation (does the AR browser show 2D, static 3D, or dynamic 3D information?); and
5. tracking and registration methods (how does the AR browser position itself in space?).

Based on this initial work, Butchart (2011b) incorporated additional criteria including user actions and API availability, which weigh more on the social aspect of mobile AR browsers, to provide standards for evaluating mobile AR browsers.

Given these initial efforts, there are currently no existing guidelines that could be used to systematically develop and consistently assess AR-integrated LBSNs (Schmalstieg et al., 2011). Therefore, the following development and evaluation guidelines for AR-integrated LBSNs are proposed. It needs to be noted that, different from the previous frameworks of mobile AR browsers (Langlotz, Nguyen, Schmalstieg, & Grasset, 2014; Langlotz et al., 2012; Vico, Toro, & Rodríguez, 2011), these guidelines do not describe specific system architectures or designs of AR-integrated LBSNs. Similarly for Vera and Sȧnchez (2016), which highlights essential categories and components that aim solely for successful AR-LBSN usage and development. These guidelines provide insights into the development and evaluation of AR-integrated LBSNs and will set the basis for future GIScience-based application developments.

These GIScience-oriented guidelines contain three major categories that should be considered when fusing AR and LBSNs: visualization, functionality, and ethics. These categories and associated core concepts are outlined and explained in the following subsections (Figure 7).

4.1 | Category 1: Visualization

Visualization is one of the most prominent features of AR (i.e., it overlays virtual objects onto reality). Therefore, as AR and LBSNs are integrated together, it is important to assess how existing and newly created information in the LBSNs may be visualized. Four components are identified for the visualization category.

- *Dimensionality*: Examines if information in the LBSN is visualized in two or three dimensions. 2D information would include images, video, and text that adhere to surfaces (i.e., walls, doors, windows, etc.). 3D information would visualize 3D objects and these objects would be created and positioned anywhere in a location (e.g., historic marketplace, tourist attraction, open-air concert).

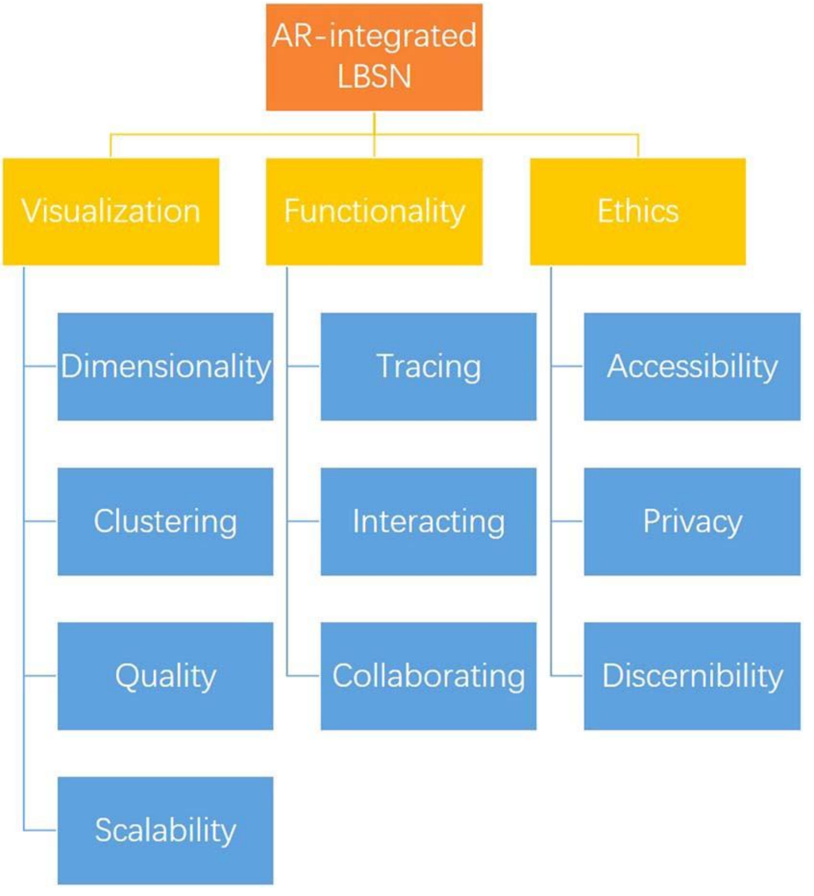

FIGURE 7 Conceptual framework of an AR-integrated LBSN

- *Clustering*: Assesses if AR content in LBSNs can be properly grouped for visual clarity. It is important to cluster multiple postings (photos, text, etc.) in one location when necessary in order to generate a visually balanced appearance and avoid filling up a user's smartphone screen. Sekai Camera is an example where clustering was not applied and AR content crowded the visual display. Thus, the product failed in the mass market, even after having received rave reviews from technology experts.
- *Quality*: Evaluates the overall visual quality and resolution of AR content in LBSNs. Depending on the application purpose, AR content might be visualized at different resolutions and varying dimensionality, aggregated or generalized. Therefore, developers need to balance the computational cost, complexity, and visual output properly.
- *Scalability*: Outlines how AR information should be displayed at different geographic scales. Although AR is often embedded in a hyper-local context, users may sometimes want to apply the technology to larger areas. An individual user may use AR to add a memo on the fridge surface, whereas a city government may use AR to show boundaries of city districts. Developers need to work with different sensors and algorithms to ensure that AR information can be geo-registered and displayed smoothly at different geographic scales.

4.2 | Category 2: Functionality

Being more than a visualization technique, AR provides a new way of interacting with the surrounding environment. Users already use various functions of LBSNs, such as publishing personal opinions, chatting with friends, organizing social events, and so on. AR can bring new insights into LBSN communications by incorporating more functionalities, three of which are listed here.

- *Tracing*: Assesses if the virtual information in LBSNs can follow the traces of objects or people in reality. A LBSN is a virtual environment where information is separated from the physical content, and AR can provide the option of registering virtual information in reality, whether stationary or mobile. For example, a user may choose to leave a stationary message in a public space or to create a mobile virtual marker that follows himself/herself for others to see. Effective indoor and outdoor positioning techniques would be key to the successful implementation of this functionality.
- *Interacting*: Evaluates how users can interact with AR-based information via different techniques in a LBSN. For example, a simple interaction could be based on scanning QR codes, and a more complex function would be to recognize predefined keywords or images. Ultimately, users can expect to directly extract or post virtual information to/from any object or human in reality.
- *Collaborating*: Reviews how users can collaborate on projects, events, and games in an AR-integrated LBSN. LBSNs allow people to work together and AR technologies greatly enhance people's collaboration abilities. Relevant functions range from message sharing and event organizing to street art creation. LBSN users can expect to utilize AR to maximize creative outcomes and increase efficiency for tasks in multiple fields.

4.3 | Category 3: Ethics

As a new technology gradually being adopted by society, there are inevitable ethical concerns involved in this process. To provide some insights on the matter, the following ethical concerns for developers and researchers need to be considered:

- *Accessibility*: Evaluates the accessibility and representativeness of data generated in AR-integrated LBSNs. The integration of AR and LBSNs could bring an influx of AR content which is useful for various data-analytical approaches, such as behavioral studies, market analysis, and so on. Developers should consider ways to store and maintain the AR data safely and provide mechanisms for data contribution, retrieval, query, and classification. Several questions are unanswered: How can we make AR-integrated LBSNs more accessible to the public? How can we promote fairness in the creation and publication of AR content? To answer these questions, user-friendly design and openly accessible data should be emphasized by both developers and users.
- *Privacy*: Examines if there are any mechanisms of information filtering in LBSNs. Can a user limit some AR content to a particular group? Can a user choose not to see what disturbs him/her? Every user may see the virtual landmarks created by the city government, while a user's personal messages, pictures, and videos may be visible only to his/her friends. Traditionally in LBSNs, information can be filtered by users' relationships (messages can only be viewed by friends) or content (a user can choose to see only topics of interest). Due to the hyper-local nature of AR content, developers may add geographic proximity as another filter to protect users' privacy.
- *Discernibility*: Assesses if virtual information can be recognized and distinguished from reality. As AR technologies advance and popularize, people may confuse virtual objects with real objects. This can be a caveat as some AR information may be dangerous to careless users, for instance virtual roadblocks or stairs. In addition, there may be safety concerns if a user is too absorbed (present) in the virtual world. Therefore, there need to be effective solutions to help users discern virtual objects in AR.

5 | CONCLUSIONS

While AR-integrated LBSNs have been developed and shown promise to become mass market products, there are still several barriers to gaining popularity in society. For example, in-situ authoring and editing of 3D objects is still a challenge to many devices. In addition, the lack of light, wearable display devices means that users constantly need to hold their smartphones or tablets at particular angles to see and interact with virtual information. This handling issue is a major hindrance of AR browser usage, and could be overcome by wearable devices and multimodal interaction modes. Although AR-integrated LBSNs are still at the innovation/early adoption stage, researchers in the GIScience community need to be aware of the potential impacts and research and development opportunities. This article has reviewed the status quo of AR-integrated LBSNs and outlined how the GIScience research agenda could be enriched in aspects of data conflation, platial GIS, and multimedia storytelling. Specific questions that arise are:

1. Can ambient information in AR-integrated LBSNs assist spatial data matching/clustering?
2. Can AR-integrated LBSNs reveal different characteristics of places?
3. What is the fundamental difference between AR and other social media in terms of multimedia storytelling?

Moving forward, our research will first tackle the data conflation question by looking for statistical correlation between the ambient information and the primary information in AR-integrated LBSNs. We utilize data from Wallame, an existing AR-integrated LBSN, to probe any statistical correlation between characteristics of user-generated content and the surrounding environment. The following approach will be taken:

1. Distinguish ambient information ("backgrounds" in pictures) and primary information (text/picture generated by users).
2. Summarize ambient information with meaningful descriptions (e.g., indoor/outdoor, simple/complex, colorful/plain (or calculate the hue directly), etc.) and do the same for primary information (e.g., sentiment, length, etc.).
3. Find if there are statistical correlations between tags or characteristics between ambient information and primary information.
4. Find if such statistical correlations vary in space and time.

Secondary research goals include developing an analytical approach that would provide more insights to understanding platial GIS and the impacts of localness on user behavior in social media. Future studies will allow us to discover the impacts, requirements, opportunities, and values of AR-integrated LBSNs in GIScience.

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