Environmental Modelling and Software 109 (2018) 380–389

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

# Mobile Augmented Reality for Flood Visualisation

Paul Haynes, Sigrid Hehl-Lange*, Eckart Lange**

*Department of Landscape, University of Sheffield, Floor 13, The Arts Tower, Sheffield, S10 2TN, UK*

ARTICLE INFO

*Keywords:*
Mobile augmented reality
Flood visualisation
Browser
Authoring
Mobile
Real time flood modeling

ABSTRACT

Mobile Augmented Reality (MAR) for environmental planning and design has hardly been touched upon, yet mobile smart devices are now capable of complex, interactive, and immersive real time visualisations. We present a real time immersive prototype MAR app for on site content authoring and flood visualisation combining available technologies to reduce implementation complexity. Networked access to live sensor readings provides rich real time annotations. Our main goal was to develop a novel MAR app to complement existing flood risk management (FRM) tools and to understand how it is judged by water experts. We present app development in context of the literature and conduct a small user study. Going beyond the presented work, the flexibility of the app permits a broad range of applications in planning, design and environmental management.

## 1. Introduction

Appropriate use of tools for visualisation in flood risk management (FRM) depends on the problem at hand. In particular, flood visualisation often employs inundation mapping methods similar to those reported in Maidment et al. (2016). Systems such as the Iowa Flood Information System (IFIS) web platform (Demir and Krajewski, 2013), for example, combine inundation maps, sensor readings, and other data, to inform community flood risk assessors (FRA's). These are important tools in FRM providing clear orthographic views of potential risks over wide areas which help facilitate expert analysis.

Virtual Reality (VR), Augmented Reality (AR), and more recently Mobile AR (MAR) (Chatzopoulos et al., 2017) and Citizen Science (Montargil and Santos, 2017; O'Grady et al., 2016; Degrossi et al., 2017) create new opportunities to investigate alternative modes of visualisation and interaction for citizen, volunteer, and expert FRA engagement. This is important due to an increased need to communicate flood risks as a precautionary measure (Hagemeier-Klose and Wagner, 2009). In this direction our main goal is to firstly develop a MAR app to enable the user to track an unspecified location, populate it with building geometry, and visualise an augmented reality flooding of the environment. Secondly we seek to understand how such an app is received by water experts. Hence, we seek to apply the aforementioned technologies to FRM, in particular how AR may be applied and how it is received by FRA's as a complementary flood visualisation tool as part of the FRM process. It is important to note that we do not seek to replace existing FRM tools, but to enhance them using immersive AR technology and to investigate the usefulness of such tools to support discussion about planning proposals.

Previous works have identified user preference towards immersive 3D visualisation (Gill et al., 2013) and experimental mobile applications were designed to take VR into the field (see e.g. Gill and Lange, 2015). Unlike laboratory-based 3D and VR simulations MAR offers new levels of engagement linking simulations with an on-site experience. Nowadays, powerful smart phones and emerging technologies such as MAR provide an opportunity to immerse the user in a visualisation whilst simultaneously experiencing the observed world environment. Observed and augmented realities may be perceived separately or together, depending on how the user chooses to experience the AR. A user, for example, may choose to intentionally note differences between the observed and augmented realities, or engage directly with the augmented reality in place of the observed reality. In general, AR presents a range of benefits to the planning and design process (Lange, 2011) such as location based information applications to support understanding of landscape futures and the environment. Bishop (2015), for example, demonstrates a variety of potential prototype applications to urban and landscape planning, including a simple prototype flood app.

Mobile devices with 3d-graphics capabilities are increasingly ubiquitous, but their potential use in landscape and urban planning has hardly been touched upon, which we seek to explore. Grainger et al. (2016) emphasize the need for environmental data visualisation for non-scientific contexts, such as public engagement and expert application in the field. Morgan et al. (2010) presented workshop-based

* Corresponding author.
** Corresponding author.
*E-mail addresses:* s.hehl-lange@sheffield.ac.uk (S. Hehl-Lange), e.lange@sheffield.ac.uk (E. Lange).

https://doi.org/10.1016/j.envsoft.2018.05.012
Received 29 March 2017; Received in revised form 8 May 2018; Accepted 21 May 2018
1364-8152/ 

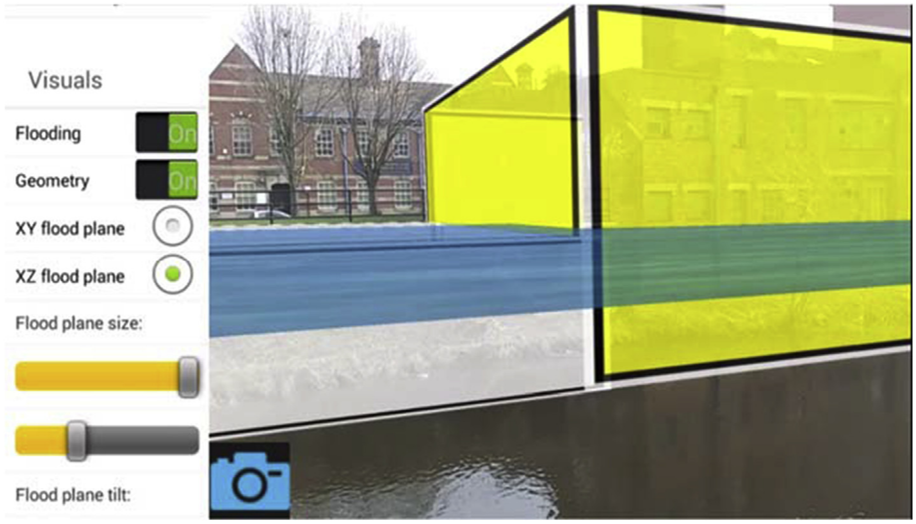


**Fig. 1.** First prototype showing scaled and translated geometry, with flood plane enabled.

rapid prototyping of urban river corridors using 3D interactive real time graphics, where lab-based modeling and visualisation software (SketchUp and Symmetry 3D) was used to prototype models for the Urban River Corridors and SUstainable Living Agendas (URSULA) project. In later work Gill and Lange (2015) explored on site VR visualisation of planning and design models where complex visualisations, ordinarily viewed on laboratory projectors, were "streamed" to a remote smart device and viewed in a web browser, bringing mobile VR to the field via portable lightweight smart device technology.

Traditional support and risk management systems appear predominantly desktop or lab based making use of inundation maps (Maidment et al., 2016) with systems such as the IFIS (Demir and Krajewski, 2013) mentioned earlier. On the other hand Amirebrahimi et al. (2016), for example, presented decision support for the evaluation of building risks in flood prone areas, with 3D visualisations of water flow around, and evaluation of damage to, new builds. Van Ackere et al. (2016) showed web-based flood damage visualisations of large coastal regions, with the aim of encouraging "… people to mitigate and adapt to climate change."

An early AR environmental management system developed by Romão et al. (2004) was Augmented Environments (ANTS), a system of technological infrastructure which augmented contextual information with physical structures and natural elements within the environment. Infrastructure consisted of a wearable laptop, a head mounted display (HMD), motion tracker, video camera, GPS system, and mobile phones for communications. Pilot applications included monitoring water quality levels, visualising temporal evolution of landscape pasts and futures, and sub-soil structure visualisation. Except for HMD's, smart phones are, remarkably, sophisticated enough to contain all this infrastructure in a single lightweight device, with huge potential for applications to environmental management, planning and design. Bishop (2015), for example, presents a variety of AR applications related to understanding landscape futures. One such application is a MAR flood visualisation concept app in which a terrain model of the Snowy River flood plains was statically clipped above one metre. Manual positioning of the clipped geometry achieved a perceived alignment of terrain model and live image feed through the camera of the mobile phone with a flood visualisation one metre in height.

On site (in situ) modeling is a difficult problem, and potentially important to environment, planning and design applications since decisions made in the field, e.g. the inclusion of design features, might otherwise be overlooked in a laboratory setting (Lange, 2011). In particular, a major problem in AR is that of registering points in the real world with points on the device display and displaying 3D graphics correctly in perspective (e.g. see Chatzopoulos et al., 2017). One solution demonstrated by Demir (2014) in lab-based AR used fiducial markers to augment a 3D model of pre-defined scenarios in which students could control environmental parameters to learn about hydrological processes such as flooding and flood damage. An HMD (Oculus Rift) option enabled users to experience the visualisation stereographically for an alternative immersive experience. Systems which use fiducial markers rely on known and physically placed markers to track the environment, which can be problematic in open outdoor environments (see Kato and Billinghurst, 1999). Fiducial markers often find use where inventories of objects may be identified, such as in the museum guide by Mata et al. (2011), for example.

The novelty of our approach is in combining real time population of building models, interactive flood visualisation, and integration with the WeSenseIt Citizen Water Observatory web platform (Mazumdar et al., 2016; Lanfranchi et al., 2014) for live sensor readings such as water level, humidity, and soil moisture. Overall, we aim to elucidate expert perceptions of MAR technology applied to FRM. We first present our methodology, detailing software architecture, design, and data flow, novel algorithms, testing and evaluation, then show the actual implementation of the software as an app, with results of testing and the evaluation plan. A discussion then follows and conclusions are drawn.

Supplementary video related to this article can be found at https://doi.org/10.1016/j.envsoft.2018.05.012.

## 2. Methodology

The presented work is based on previous work by the authors, shown in Fig. 1, where primitive cuboids were manually transformed into position using the touch screen (Haynes and Lange, 2016a, 2016b) to visually align with the live image feed in much the same way Bishop (2015) aligned a terrain model of the Snowy River flood plains. A constructive solid geometry (CSG) difference operation applied to building geometry and flood plane simulated water flow, where the building geometry could be made transparent, and the flood plane translated vertically to different water levels.

In the presented work we add the following functionality: (i) an improved strategy to more precisely populate a site with geometric primitives (cuboids and arches), (ii) cloud server capability for project storage/retrieval, (iii) integration with the WeSenseIt web service, (iv) water height interpolation as a function of flood plane height and predefined extremity values, and (v) real time annotation visualisation and editing, to convey historical information, evacuation routes, and real-