Computers, Environment and Urban Systems 54 (2015) 356–362

Contents lists available at ScienceDirect

Computers, Environment and Urban Systems

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

Getting virtual 3D landscapes out of the lab

Lewis Gill [a],*, Eckart Lange [b]

[a] Department of Computer Science, University of Sheffield, United Kingdom
[b] Department of Landscape, University of Sheffield, United Kingdom

ARTICLE INFO

Article history:
Received 6 August 2014
Received in revised form 26 September 2015
Accepted 26 September 2015
Available online 21 October 2015

Keywords:
On-site
Landscape visualisation
On-demand
Smartphone
Mobile
Tablet

ABSTRACT

Increasingly realistic virtual three dimensional (3D) models have been created that demonstrate a variety of landscape designs. They have supported a more collaborative and participative approach in planning and design. However, these 3D landscape models are often developed for use in bespoke virtual reality labs that tie the models to expensive graphics hardware, or complex arrays of screens, with the viewer spatially detached from the actual site.

Given the increase in prevalence of advanced "smartphone" and tablet technology with GPS and compass functionality, this paper demonstrates two methods for on-demand dissemination of existing virtual 3D landscape models using: (1) a touch based interface with integrated mapping; (2) a standard web browser interface on mobile phones. The latter method demonstrates the potential to reduce the complexity of accessing an existing 3D landscape model on-site to simply pointing a smartphone in a particular direction, loading a web page and seeing the relevant view of the model as an image. A prototype system was developed to demonstrate both methods successfully, but it was also ascertained that the accuracy of GPS positional data can have a negative effect on the browser based method.

Finally, potential developments are presented exploring the future of the technology underpinning the method and possible extensions to the prototype as a technique for increasing public participation in planning and design.

1. Introduction

Public participation is an approach for making the landscape planning and design process more inclusive. In recent decades, this approach has been adopted into government policy, for instance as articulated in the European Landscape Convention (Lange & Hehl-Lange, 2011), or in the UK Localism Act (Localism Act, 2011), which aims to devolve decision making powers to a local level, e.g. to neighbourhood planning groups. However, one of the major tasks for public participation in landscape planning and design is the dissemination of the information to the population. Typically, in the Western world, planning departments hold the records pertaining to landscape proposals and distribute this information through formal planning meetings, public displays, or by sending documentation directly to the public. Widely adopted digital connectivity via the Internet has aided this dispersal by providing online access to planning documents through local governmental planning portals. Nevertheless, Warren-Kretzschmar and von Haaren argue that when planners attempt to engage with the public, there can be a disconnection between perceived and actual participation of the public, although this can potentially be overcome through the use of visualisations (Warren-Kretzschmar & Von Haaren, 2014). In comparison to the written or spoken word, visualisations have lower barriers in terms of communicating contents thus helping to improve citizens' understanding and ability to respond towards planning issues.

Landscape visualisations are a means to graphically represent the landscape. There is a long tradition of analogue techniques including physical models, sketches and so on. In recent decades, digital representations of landscapes have become more commonplace in the communication of possible future landscape designs, with the digital photomontage (Lange, 1990) widely employed. In addition, interactive 3D landscape visualisation technologies are increasingly being used by planners and landscape designers. In 1995, Danahy and Hoinkes demonstrated interactive landscape visualisations using their POLYTRIM software running on then state of the art graphical computer hardware (Danahy & Hoinkes, 1995). Since then, digital landscape visualisations have been used to represent a variety of differing future scenarios from large scale environments (Perrin, Beauvais, & Puppo, 2001) down to highly detailed site design (Morgan, Gill, Lange, & Romano, 2009). Research surrounding interactive landscape models has tended to concentrate on techniques to improve photo-realism (House, Schmidt, Arvin, & Kitagawa-DeLeon, 1998), user immersion (Bishop & Dave, 2001) and model complexity without degrading rendering speed (Deussen, 2003). This has led to successful solutions for immersive Virtual Reality (VR) laboratories, but ones that require

---

* Corresponding author.

http://dx.doi.org/10.1016/j.compenvurbsys.2015.09.012

complex bespoke computer hardware, such as the 13 workstations and 13 projector configurations described by Zehner (Zehner, 2009). The advent of laptops with powerful graphical resources and portable projectors has meant that it is possible to move interactive 3D landscape models to multiple locations. For example, a model originally created for use in a VR lab was also used as an interactive learning tool at a natural history museum using a laptop (Morgan, Gill, Lange, & Dallimer, 2012). Internet based dissemination of interactive landscape models has also been undertaken (Shojaei, Rajabifard, Kalantari, Bishop, & Aien, 2014), but this tends to require a reasonable level of computing hardware at the client side to render the downloaded models together with the ability to navigate the model using the supplied user interface.

Thus, although there are now the tools to construct and render detailed landscape models, their intrinsic information is often locked in VR laboratories (Zehner, 2009), or may contain a barrier to use through requisite hardware and the need to learn a user interface (Paar, 2006). All of which can also make it difficult to integrate with existing online planning portals and none of these methods make it simple for the public to interrogate existing models quickly on-site. On-site access of landscape visualisations would allow the public to contrast the future vision of landscape designers with the reality on the ground and it may also help engage with more people who actively pass through a site.

In 2001, Rakkolainen and Vainio examined the usefulness of 2D maps and 3D models in a mobile environment as an aid for navigation of an unknown urban environment. The results from their trial showed both 2D maps and 3D elements were interchangeably consulted by participants (Rakkolainen & Vainio, 2001). They were hampered however by the lack of computation resource in the handsets available to them, but predicted the arrival of more computationally powerful devices.

Nowadays, new opportunities arise for transmission of landscape visualisations with the advent of ‘smartphone’ and ‘tablet’ technologies that can derive their location, have high resolution screens, internet connectivity and enough computing power available to render graphical images (Evans-Cowley, 2012). These devices are becoming increasingly commonplace and offer an opportunity to present landscape visualisation to the public in an easily accessible manner. This has been demonstrated with ‘apps’ that can overlay information on video feeds, presenting Augmented Reality (AR), e.g. Layar (Layar, 2009). However, these can suffer from occlusion issues or poor video quality (Takacs et al., 2008). Alternatively, apps are available that can present pre-prepared visualisations of future scenarios whilst on-site (Lange, 2011, Bilge, Hehl-Lange, & Lange, 2014, Priestnall, 2009). These methods can provide either the visual fidelity of VR lab based models or the interactivity of viewpoint, but not both.

Therefore, the aim of the work presented in this paper is to illustrate a method that disseminates highly detailed and interactive 3D visualisations of landscape and urban design proposals via smartphones and tablets on site. Such an approach could be highly advantageous to planners and designers (Graham-Rowe, 2011), both in potentially reducing costs of delivery and increasing inclusiveness in decision making.

In Section 2, a theoretical discussion is presented that explains how the new method relates to existing visualisation techniques. Section 3 details the implementation of several different prototypes that provide on-site visualisations by re-using existing virtual 3D landscape models. Section 4 highlights the results of using the prototype system out at a location. Finally, future work, discussion and conclusions are presented.

2. Theory

Mobile phone ownership in Europe has increased rapidly in the last decade, but the type of devices being sold is changing. UK Office of Communications (OFCOM) data states that adoption of a smartphone (a mobile phone that has a web browser and internet connectivity) very rapidly increased in the UK population to 61% in 2014 (UK Office of Communications (OFCOM) 2015). These devices have a high-resolution colour display, increasingly rapid data connections, Global Positioning Service (GPS) and compass.

Therefore, with the general population increasingly using smartphones, one potential method to improve public participation in landscape design would be to provide access to the visualisations usually associated with public participation via their smartphone or tablet device. This would continue the trend of providing planning portals for people to access, but rather than access being via a static computer, they would be able to view them when and wherever they had mobile data connectivity. In other words, the visualisations would come to the person on site, rather than people going to them. This would allow the public to reference a 3D landscape model from any position and would avoid the situation of only providing a handful of chosen 3D views of a proposal (Graham-Rowe, 2011), which could be critical to judging the visual impact of a proposal. Large-scale adoption of this technique has the potential to create a more democratic method of access to landscape planning and design scenarios.

This theoretical system can even be taken one step further. With the GPS and compass combining to allow the smartphone to determine its position and direction and given that virtual models are correctly georeferenced then it is possible to map the real world smartphone location to the corresponding location in one or more virtual landscape proposals. This real to virtual world mapping provides the possibility of delivering on-site visualisations matched to the current view of the user, which would provide a very simple method for comparing the current situation with any future proposals.

Smartphones are increasingly equipped with more advanced graphical rendering capabilities, so one solution would be to provide the ability to download virtual models to the smartphones and render these locally to the user. However, due to memory, power, size and thermal constraints, the computing power of mobile devices is unlikely to match that of graphic workstations. Similarly, the quality of any visualisation rendered locally, including the AR approach, is unlikely ever to match that of the VR labs.

One alternative approach is to re-use existing virtual models based on powerful remote server farms and let them render the visualisations requested by the user and transmit these to the user over mobile data networks. This would allow higher fidelity visualisations, but may slow the overall interactivity with the virtual model, making user interaction dependent on the data connection round-trip times.

In order to place this new theoretical system in context, the presentation of virtual 3D landscape models can be grouped into six methods:

1) VR lab
2) PC mobile
3) Internet PC
4) AR mobile
5) Pre-prepared mobile
6) On-demand mobile

“VR lab” encompasses non-transportable immersive environments built to display interactive virtual landscape visualisations. “PC mobile” groups together approaches where the virtual model can be taken to different sites using a PC laptop or transporting a desktop PC. “Internet PC” represents attempts to disseminate interactive 3D landscape models via the Internet to home PCs for local rendering and viewing. The complexity of the models transmitted in this way can vary based on how much must be downloaded and is dependent on sufficient hardware being available on the home PC for interactive viewing. “AR mobile” categorises all attempts to render and overlay a model over the real world using a mobile device. “Pre-prepared mobile” represents pre-rendered visualisations available for certain areas of a design proposal. Finally, the proposed “on demand mobile” defines any system

Table 1
Landscape models presentation methods and their capabilities.

Visualisation technology	On site	Potential audience	Model complexity	Interactivity	Data connectivity
VR Lab	No	Small	High	High	No
PC mobile	Yes	Small	High	High	No
Internet PC	No	Large	Low to High	Low to High	Yes
AR mobile	Yes	Large	Low	High	Yes
Pre-prepared mobile	Yes	Large	High	Low	Yes
On-demand mobile	Yes	Large	High	Low to High	Yes

that would deliver user specific imagery from a remote 3D virtual landscape model to a mobile device.

To understand the advantages and disadvantages of this range of approaches, the following criteria of interest were applied (Table 1):

- whether the method can be used on site
- the size of the potential audience the visualisation method can address
- the level of detail and area of context that can be held in the model
- how interactive the visualisations are
- whether a data connection is needed to access the visualisations

The idealised presentation system is one that provides on-site visualisations, gives access to a large potential audience, displays high levels of model complexity, is highly interactive and is without the need to use data connectivity. However, it can be seen that no approach satisfies all of these. Each method of presentation ends up trading off some capability for another.

Regarding all the options, the "on demand mobile" solution did present an approach for delivering a high level of model complexity on site and to a large audience, albeit at the cost of having a dependency of servers and data network, which will determine the level of interactivity. As there was no known solution for the on-demand mobile approach, a prototype was developed to illustrate this concept.

The results of a study by Paar into the adoption of 3D visualisation software in Germany highlighted that "ease of learning" is highly important to successful adoption (Paar, 2006). Thus, any technology that provides this visualisation on-demand functionality and aims for widespread adoption should also present it in a user interface that requires minimal learning by the user to operate. Therefore, a design goal for the prototype was also to make user interaction as simple as possible.

3. Method

For this study, detailed virtual landscape models were available. However, due to the complexity and size of these models they would not render on the mobile devices available. Therefore, it was decided to attempt to implement the "streaming" of visualisations to the remote smartphones. This ensures the same graphical style of visualisation that would have been available to a user in the VR lab viewing the same model. The prototype was developed as a client/server architecture where the mobile "clients" would request visualisations from a "server" computer. To re-use the existing models, three pieces of software development were undertaken: a visualisation server hosted in existing landscape visualisation software; a tablet based "app"; a web browser based interface for mobile devices. An overview of the implemented architecture can be seen in Fig. 1. Each element is further detailed below.

3.1. Visualisation server

The visualisation server provided the core functions to allow mobile applications to connect and request visualisations. It was developed to take a bespoke communication protocol over TCP/IP that allowed the tablet app to communicate with it, but also it provided a rudimentary web server component. The visualisation server was written in C++ and was run as a plug-in to an existing piece of visualisation software called Simmetry3d (Deliverance Software, Simmetry3d, 2006), which hosted the virtual models. Once Simmetry3d had loaded a georeferenced virtual 3D landscape model, it was possible for clients to connect and request visualisations.

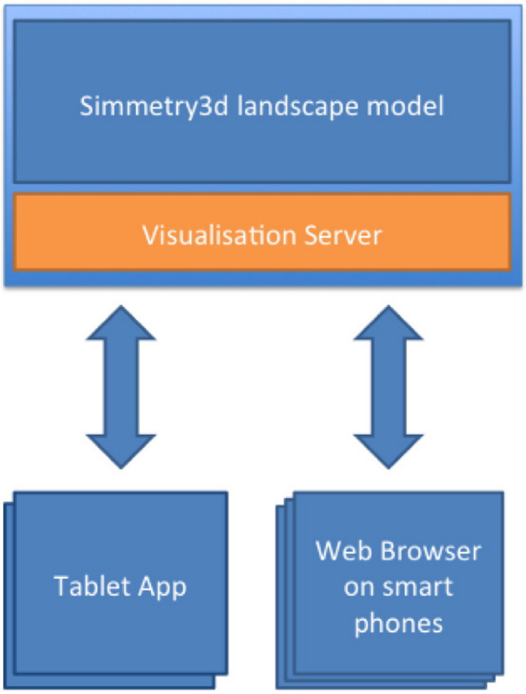

Fig. 1. Prototype architecture.

The embedded web server allowed any web browser to use the standard HTTP protocol to request a JPEG image from the 3D model. The web server component would receive a URL request with a latitude, longitude and direction as parameters, convert these to model coordinates, render the appropriate image data for that position using a Simmetry3d API call and, finally, return the generated image data to the user. Simultaneous requests could be made to the web server, but the 3D view images were all rendered in the main Simmetry3d thread in response to user requests whilst threading semaphores were used to coordinate the return of image data back to the appropriate user request thread. To provide different proposal options, multiple 3D models are often created. By loading these into separate instances of Simmetry3d (with the required visualisation server plug-in) on multiple physical servers, it was possible to provide a client with multiple visualisations.

3.2. Tablet app

The tablet app was initially developed to provide a method for navigating a Simmetry3d model in the VR lab using touch-based interface and 2D mapping. When the app was connected to a visualisation server, the server would render a top-down site plan image of the landscape model, which was sent to the tablet and overlaid on to existing satellite imagery, as shown in Fig. 2. The current position of the camera in the visualisation would then be highlighted in the tablet view via a red circle with a line denoting direction (zoomed screenshot shown in Fig. 3). It operates in a similar fashion to the more tangible "lightwheel" interface approach of Werner et al. (Werner et al., 2005).

The user was able to press a finger on the site plan to select a new position with a swipe to define the direction of view. The view in the interactive visualisation running in Simmetry3d would be set to the

Fig. 2. Tablet interface for viewing and controlling the position in a Simmetry3d visualisation.

given height in the model at that position. For example, if the user selected a position over a building the view would be set to the top of that building. It was also possible to provide movement buttons to allow movement of the view laterally and vertically.

Although the initial tablet app could be used in the VR lab or in conjunction with a laptop, it still meant access to the visualisations required physical access to the computer running the 3D visualisation software. Should a designer want to work remotely with the prototype, this would mean that they would have to carry a laptop. The missing element was the ability to transmit images generated from the 3D model to the tablet. The implementation of this functionality allowed the tablet interface to receive an image of the 3D model on-demand. The tablet interface was extended further to allow connections to multiple models (each detailing a different scenario), running on separate servers, so that synchronised images for all scenarios could be downloaded to the tablet app. Once these were available, the user could move a finger vertically on the tablet to blend between the images as a method of comparing differences at that viewpoint.

Fig. 3. Tablet interface for viewing and controlling the position in a Simmetry3d visualisation.

The tablet app showed the current position of the device on top of the mapping view. This meant that a user of the tablet could go on to site and use the point and click interface to choose a position and direction in the connected visualisations. Next, they could then acquire the same view in the connected scenarios as they themselves had of the site. An example of the tablet app being used on-site can be seen in Fig. 4.

After discussions with the developer of Simmetry3d, that visualisation server was extended to also allow generation of a 360° panorama at a point, which meant a user could download an interactive panorama to the tablet. An interactive panorama responds as the user moves a mobile device around in 360°. Based on the position and direction of the host device, the image shown on screen alters to give the user a "window" into the panorama. The panorama file was requested in the same way as the HTTP image request was processed and the resulting file sent from the web server back to the tablet. Then it could be launched from the tablet application into an existing panorama viewer, Walkabout 3d (Deliverance Software, Walkabout3d, 2009). This was designed to give a more interactive experience with the 3D model than multiple image requests for an individual location would provide.

3.3. Smartphone web browser based visualisations

Whilst it would have been possible to provide an interface similar to that implemented on the tablet app, it would have to account for the significantly smaller screens of smartphones. Also, using that interface would still require the user to understand a site plan, demanding user interaction to ascertain the required viewpoint. Anyone accessing without understanding the site plan, would meet a barrier to using the system. As stated previously, any attempt to include more people in public participation via technology should aim to reduce the barriers to accessing planning information. Therefore, rather than accessing the visualisations using a site plan, a new interface was constructed that utilised the position and direction information accessible in a standard smartphone web browser.

By combining the web server in the visualisation server with smartphones that have access to location information available via JavaScript objects, it was then possible to provide a standard URL that a user types into their phone browser. The corresponding view was then returned to the user as a standard HTML document. This made the user interface as simple as pointing a phone in a particular direction and loading a web page. An example of how this looks to a user is shown in Fig. 5. When changing the position or the viewing direction a new view of the 3D model can be requested by simply refreshing the web page. This action automatically sends the information of the new position and direction to the web server and results in an updated image being loaded in the web browser.

It was also possible to provide access to multiple scenarios from one web page. For this, a master web server had to be configured with the network address to the other scenario web servers. The server handling the user request would generate the appropriate view. Simultaneously, it would also hand off to the other scenario servers to do the same for the position and direction parameters. Finally, when the master server had collated all the appropriate data, it would then return the image data to the mobile device. Once the images had been downloaded, it was then possible to blend between the scenario images with a vertical finger gesture as a method of comparing the differences between designs, in a similar fashion to the tablet application. Reducing the client requirements to a standard HTTP request and response makes it possible to host a visualisation server on any computer hardware capable

Fig. 4. Tablet device displaying an on-demand visualisation on-site© Sigrid Hehl-Lange.

of rendering the model, which means planning departments would be able to host the model online.

4. Results

The tablet app and the mobile web browser application were tested remotely and connected to several existing virtual 3D landscape models in a central area of Sheffield. It proved possible to use both the tablet app and the web browser on-site to navigate and view multiple remote 3D landscape models via a 3G data connection. The production and transmission of the 3D views would take several seconds due to the rendering of the model to an image and the transmission speeds of the mobile data network. The panorama files took even longer to produce as they require multiple views to be rendered and the resultant file size was on average approximately 10 times larger. This system performance cannot therefore be deemed fully interactive, although it did provide an easy method of viewing the model remotely and within the context of the site.

Using the GPS and the compass automatically to both ascertain and transmit location and direction was possible. When the mobile device

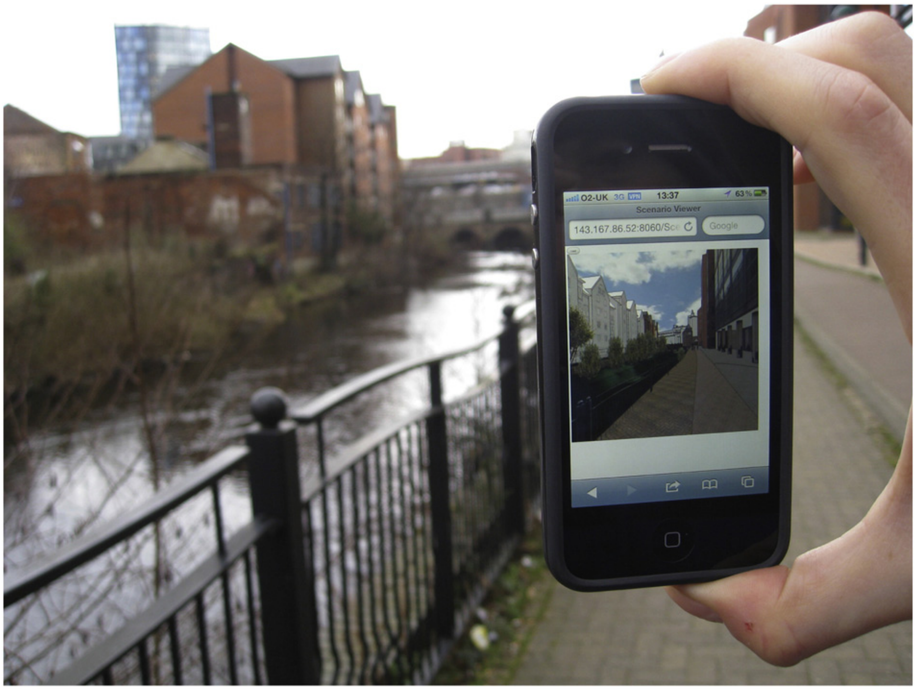

Fig. 5. Smartphone showing an on-demand visualisation of a redevelopment proposal through a web browser.

accurately determined the GPS position, it provided a very easy to use method of accessing a 3D landscape model. However, there can be inaccuracy in the detected position, which could mean when standing by the riverside, the server returned a view of the model from one or two metres into the river. Moving position would often rectify this.

5. Discussion

It has been demonstrated that it is possible to disseminate visualisations from existing detailed virtual 3D landscape models both on-demand and on-site through touch based user interfaces. Given this, it seems a sensible strategy to ascertain whether it does indeed provide benefits over more traditional forms of public consultation, or over VR labs with 3D navigational interface devices.

The different methods for disseminating virtual 3D landscape models all have varying strengths and weaknesses. For example, it must be clearly stated that one obvious drawback to the on-demand streaming system is that fast mobile data networks do not provide universal coverage. So, if a proposal were located outside data network coverage, the above system would fail to operate. Visualisation on-site could still be possible if an ad-hoc wireless network were to be set up to a base computer that hosted the model and the user stayed in range.

It may mean this on-demand streaming system is currently more suited to urban sites rather than more rural ones. In this sense, at the moment the presented software developments are more suited to design-related urban projects, such as new housing, a new urban park and so on, but less suited for projects in rural areas that typically require assessing their impact including e.g. wind parks, hydro power projects, etc. However, as was mentioned in the Results section signals can suffer from inaccuracy, especially in dense urban or forested environments. Therefore, the layout of urban site being visualised may have a significant effect on the use of any system (AR, or on-demand streaming) that relies on accurate location determination. The introduction of higher accuracy GPS systems, such as the European Galileo project (Ji et al., 2010), means the positioning in smartphones may become more precise and overcome this issue. Another option would be to augment the GPS location using information gleaned from sensors based on the mobile device (Dalla Mura, Zanin, Andreatta, & Chippendale, 2012).

In either situation, urban or rural, projects can be highly contentious and would benefit from improved public participation. In the setting of a VR lab the stakeholders involved in a participatory process are removed from the actual site. It is not only hard for them to imagine the context but also other sensory experiences, other than visual, are normally excluded. In contrast, a prototype as it is presented here allows consideration of not only the visual appearance of a project, but also of other sensory experiences while on site (Lindquist & Lange, 2014). The authors suggest that the suitability of each method of visualisation delivery be examined based on the type of proposal, the sensitivity of the proposal, the level of detail contained in the available models, screen size and any other relevant criteria.

Being able to access multiple options in a planning and design seems extremely important as it allows a comparison of alternatives and highlighting of differences at that viewpoint. Further research to determine how to present multiple design options to the user for each of the different visualisation delivery methods would seem another sensible direction to pursue.

6. Future work

The prototype as currently implemented would not provide a highly scalable solution for high demand scenarios as it relies on the Simmetry3d API to move the viewer to a particular position and then render that view, so requests for visualisation by multiple clients would be queued as the server processed each request one at a time. However, this could be overcome in the future with a multi-threaded rendering solution.

There are a number of possibilities for extending the prototypes presented. The integration of social networks and online planning portals to the web site interface on the smartphone provides the possibility of allowing users to give their feedback on landscape proposals instantaneously. Recording locations in the proposal when people request views may provide insight into areas of concern or popularity. This data would end up being able to produce tracking maps that could be overlaid on the 3D model to give designers and planners an insight into popular, or potentially controversial areas or aspects of a design, especially in conjunction with an analysis of comments and feedback on social networks. Although graphics hardware on mobile devices continues to improve, it is likely the geometric complexity of 3D landscape models will continue to remain beyond the capacity of mobile devices to render interactively. In addition, the rollout of 4G connectivity and other future technologies will reduce the time taken in delivering on-demand streamed visualisations. Therefore, to further enhance the interactivity of feedback to the user it may be possible to consider a “cloud” based rendering solution that sends video to the client device rather than geometric data, such as the scheme presented by Lamberti and Sanna (Lamberti & Sanna, 2007).

It is worth stating that, as this on-demand prototype uses standard Internet protocols (HTTP over TCP/IP), this method is not limited to merely mobile browsers. It could easily be used in standard web browsers too, but some method for specifying location and direction would have to be introduced. Another usage pattern could be to allow users to connect their mobile devices to an interactive walk-through running in the VR lab and be able to save views without having to interrupt proceedings, or for use in further discussions later away from the VR lab.

7. Conclusions

It is now possible to create detailed visualisations of possible changes to our environment through interactive 3D landscape models. These can be shared with the public in one of the six methods (VR lab, PC mobile, internet PC, AR mobile, pre-prepared mobile, on-demand mobile) detailed in this paper. Each method has advantages and disadvantages associated with it, but determining which method to use in which circumstance is not yet clear.

3D models were previously restricted to being explored in a remote lab or office environment, in that the 3D or virtual environment is mainly restricted to a purely visual representation. While an aural component can also be part of the representation (Lindquist & Lange, 2014), being on site provides a multi-sensory environment that is very difficult to recreate faithfully in a remote location. This isolation from the actual site can lead to divergent responses to visualisations (Wergles & Muhar, 2009). The approach presented here allows interactive exploration of landscape visualisations amongst the current context.

The different methods that can be pursued open up a number of routes in research, development and application that need exploring further (Gill, Lange, Morgan, & Romano, 2013). These efforts need to involve the general public, experts in software engineering and the planning and design disciplines in order to understand the suitability and to get maximum benefit of these methods for public participation in planning and design.

Acknowledgements

This paper is based on work undertaken within the URSULA project, funded by the UK Engineering and Physical Sciences Research Council (Grant number: EP/F007388/1). The authors are grateful for this support, and to Sigi Hehl-Lange and Ed Morgan who took the photographs of the site visit and helped develop the Simmetry 3d API respectively. The views presented in the paper are those of the authors and cannot be taken as indicative in any way of the position of the funders or of colleagues and partners.

References

Bilge, G., Hehl-Lange, S., & Lange, E. (2014). Use of mobile devices in public participation for the design of open spaces. *Peer reviewed proceedings digital landscape architecture 2014* (pp. 309–314). ETH Zurich, Swiss Federal Institute of Technology.

Bishop, I., & Dave, B. (2001). Beyond the moving camera: Systems development for interactive immersive exploration of urban environments. *Proceedings of computers in urban planning and urban management, Honolulu* (pp. 18–21).

Dalla Mura, M., Zanin, M., Andreatta, C., & Chippendale, P. (2012). Augmented reality: Fusing the real and synthetic worlds. *Geoscience and remote sensing symposium (IGARSS), 2012 IEEE International* (pp. 170–173).

Danahy, J., & Hoinkes, R. (1995). Polytrim: Collaborative setting for environmental design. *The global design studio* (pp. 647–658). Proc. CAAD Futures, National University of Singapore.

Deliverance Software, Simmetry3d. (2006).Sheffield, UK: Deliverance Software Ltd.

Deliverance Software, Walkabout3d. (2009).Sheffield, UK: Deliverance Software Ltd.

O. Deussen, “A framework for geometry generation and rendering of plants with applications in landscape architecture,” Landscape and Urban Planning, vol. 64, no. 1–2, pp. 105–113, Jun. 2003.

Evans-Cowley, J. (2012). There's an app for that. *International Journal of E-Plant Research, 1*(2), 79–87 (32).

Gill, L., Lange, E., Morgan, E., & Romano, D. (2013). An analysis of usage of different types of visualisation media within a collaborative planning workshop environment. *Environment and Planning B: Planning and Design, 40*(4), 742–754.

D. Graham-Rowe, “Not in my backyard! App to spot eyesores in the making,” New Scientist, no. 2806, p. 23, 07-Apr-2011.

D. H. House, G. S. Schmidt, S. A. Arvin, and M. Kitagawa-DeLeon, “Visualizing a real forest,” IEEE Computer Graphics and Applications, vol. 18, no. 1, pp. 12–15, Jan. 1998.

Ji, S., Chen, W., Ding, X., Chen, Y., Zhao, C., & Hu, C. (2010). Potential benefits of GPS/GLONASS/GALILEO integration in an urban canyon — Hong Kong. *Journal of Navigation, 63*(04), 681–693.

F. Lamberti and A. Sanna, “A streaming-based solution for remote visualization of 3D graphics on mobile devices,” IEEE Transactions on Visualization and Computer Graphics, 13, 2, pp. 247–260, Apr. 2007.

Lange, E. (1990). Vista management in Acadia National Park. *Landscape and Urban Planning, 19*(4), 353–376.

E. Lange, “99 volumes later: We can visualise. Now what?,” Landscape and Urban Planning, vol. 100, no. 4, pp. 403–406, Apr. 2011.

Lange, E., & Hehl-Lange, S. (2011). Citizen participation in the conservation and use of rural landscapes in Britain: The Alport Valley case study. *Landscape and Ecological Engineering, 7*(2), 223–230.

Layar. New York, NY, USA: Layar, 2009.

Lindquist, M., & Lange, E. (2014). Sensory aspects of simulation and representation in landscape and environmental planning: A soundscape perspective. In A. Contin, P. Paolini, & R. Salerno (Eds.), *innovative technologies in urban mapping* (pp. 93–108). Springer International Publishing.

Localism Act (2011). http://www.legislation.gov.uk/ukpga/2011/20/contents/enacted ([Online]. Available:, Accessed: 22-May-2015)

Morgan, E., Gill, L., Lange, E., & Romano, D. (2009). Rapid prototyping of urban river corridors using 3D interactive, real-time graphics. *Proceedings digital landscape architecture 2009* (pp. 198–205). Malta: Anhalt University of Applied Sciences.

Morgan, E., Gill, L., Lange, E., & Dallimer, M. (2012). Integrating bird survey data into real-time 3D visual and aural simulations. *Digital landscape architecture* (pp. 492–498) (Berlin).

P. Paar, “Landscape visualizations: Applications and requirements of 3D visualization software for environmental planning,” Computers, Environment and Urban Systems, vol. 30, no. 6, pp. 815–839, Nov. 2006.

L. Perrin, N. Beauvais, and M. Puppo, “Procedural landscape modeling with geographic information: The IMAGIS approach,” Landscape and Urban Planning, vol. 54, no. 1–4, pp. 33–47, May 2001.

G. Priestnall, “Landscape visualization in fieldwork,” Journal of Geography in Higher Education, vol. 33, no. sup1, pp. S104–S112, Jan. 2009.

I. Rakkolainen and T. Vainio, “A 3D city info for mobile users,” Computers and Graphics, vol. 25, no. 4, pp. 619–625, Aug. 2001.

D. Shojaei, A. Rajabifard, M. Kalantari, I. D. Bishop, and A. Aien, “Design and development of a web-based 3D cadastral visualisation prototype,” International Journal of Digital Earth, vol. 0, no. 0, pp. 1–20, Apr. 2014.

Takacs, G., Chandrasekhar, V., Gelfand, N., Xiong, Y., Chen, W. -C., Bismpigiannis, T., ... Girod, B. (2008). Outdoors augmented reality on mobile phone using loxel-based visual feature organization. *Proceedings of the 1st ACM international conference on Multimedia information retrieval* (pp. 427–434).

UK Office of Communications (OFCOM) (2015). Facts & figures. http://media.ofcom.org.uk/facts/ ([Online]. Available:, [Accessed: 24-May-2015])

B. Warren-Kretzschmar and C. Von Haaren, “Communicating spatial planning decisions at the landscape and farm level with landscape visualization,” iForest - Biogeosciences and Forestry, vol. 7, pp. 434–442, May 2014.

N. Wergles and A. Muhar, “The role of computer visualization in the communication of urban design—A comparison of viewer responses to visualizations versus on-site visits,” Landscape and Urban Planning, vol. 91, no. 4, pp. 171–182, Jul. 2009.

Werner, A., Deussen, O., Dollner, J., Hege, H. -C., Paar, P., & Rekittke, J. (2005). Lenné3D — Walking through Landscape Plans. *Trends in real-time visualization and participation* (pp. 48–59) (Anhalt).

Zehner, B. (2009). Interactive wind park planning in a visualization center — giving control to the user. *Proceedings digital landscape architecture 2009* (pp. 16–23). Malta: Anhalt University of Applied Sciences.