Citizen Interaction with a Digital City Twin

Enabling participation via geolocated AR technology

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Here we describe the testing of Geolocated Augmented Reality (G-AR) as a promising technical approach to convey urban design information to city authorities in order to facilitate the integration of location-based citizen feedback within a Digital Twin City (DTC) environment. Adopting citizen-centric principles can help democratise interactions with the Digital Twin, thereby enhancing public engagement with architecture and urban development proposals. The focus of the research reported here is the establishment and implementation of appropriate, commercially available, connected AR technologies to enable feedback to the digital twin. We report on initial testing to establish that the three primary intended functions of the citizen feedback system deliver the desired performance.

Keywords: *Digital Twin, geolocation, urban, democratisation, citizen-centric, smart devices.*

INTRODUCTION

Location-based augmented reality, accessed via hand-held devices, presents a technology combination that can potentially enable citizen interaction and feedback within Digital Twin City (DTC) environments.

Our aim is to devise and test a technology combination that cities could use to enable citizens to interact with the DTC model, leaving comments or suggestions. To do this we amalgamate generally available components as an accessible approach for city authorities to adopt.

We specifically focus on ARCore and the Geospatial Creator API as the primary tools for building the proposed AR system. ARCore is the software development kit (SDK) from Google for constructing augmented reality (AR) experiences. An API is an Application Programming Interface. It is a set of rules and protocols that allows different software applications to communicate with each other. In our case we need the citizen feedback data or interaction log, provided by a user when at a particular physical site, to communicate with the data that is encapsulated in a digital twin/model. In turn this means the geolocated data has be correctly synchronised with the DTC geometry.

We describe a process for evaluating the technical usability and performance of the proposed system where users give feedback by extracting data from the DTC model and returning commented data back to the DTC. Both testing and analysis of these workflows are used to validate appropriate technical roadmaps.

Cities function as interconnected social ecosystems, making it essential to define our focus. This paper emphasises the technology implementation aspects, exploring how public interaction can be effectively facilitated by applying current technological innovations.

The research has employed a combination of literature review, technical evaluations, prototype experiments and usability assessments, summarized as follows:

1. Literature review followed by technical reviews to identify suitable development tools and methods and identify critical capabilities.

2. Prototype experiments that utilize current and developing tools to implement and evaluate the effectiveness and operation of the Geolocation-based AR systems.

In the conclusion, we report on the performance of the hand-held geolocated system for three types of interaction and feedback. The first gives on-site user information. The second enables users to react and comment. The third function enables citizens to express simple 3D urban design preferences.

In this research, we primarily use the dataset defining the Wellington City Council (WCC) digital twin (Fig. 1), but when needed, employ Google's geospatial data. The WCC dataset offers detailed, real-time minimally optimised urban data tailored to Wellington's unique challenges, while Google's dataset provides broad geographic coverage and easy integration with various platforms.

Figure 1
Digital Twin of the city of Wellington

LITERATURE AND TECHNICAL REVIEW

The idea of the digital twin and the ability to provide geolocated digital information on aspects such as mapping, route-finding and asset location in the city has evolved over the past 20 years. For instance, Berridge, Koch and Brown (2003) showed the potential for mobile devices to deliver useful city information to a user when located in a city context.

Digital Twin Cities

Initially referred to as the digital city model, the term digital twin was first adopted in other industries and made its way into the urban field around 2017. At this point, it described a 3D digital model of a city, combined with animation, interaction, and viewing through various dynamic digital technologies (Mohammadi & Taylor, 2017). Generally, such environments are now called Digital Twin Cities (DTCs), City-scale Digital Twins (CDTs) or Urban Digital Twins (UDTs).

More recently, there has been a realisation that, as technological capabilities increase, the digital city twin can help guide and optimise the planning and management of physical cities. It can become an integral part of constructing smart cities, and can be a part of the delivery of a range of citizen services. Achieving this requires the integration of IoT technologies, cloud computing, big data, AI, and other contemporary technologies (Deren et al 2021). Our work responds to this potential.

City-scale Digital Twins (CDTs) have begun to support decision-making and aid in the delivery of city-level outcomes, including urban planning, management, operation, and services (Nochta et al., 2021). Urban Digital Twins (UDTs) offer a digital built environment that serves as a platform to integrate physical, cyber, and social infrastructure systems, providing a data-driven decision-making framework through various models and methods to address a range of issues. Rong et al., (2020) for instance note the application in flooding resilience, a particular issue in our case study city.

However, experts and researchers still maintain that important challenges still present themselves in relation to the efficient and appropriate exploitation of urban digital twin technology (Lei et al, 2023; Kismul et al, 2023).

Public Participation and Interaction

Despite the significant advancement in the development and application of various DTC technologies, Charitonidou (2022) notes that digital twin functions "often neglect the importance of social interactions, competition and cooperation…[and].. democracy". Community and citizen engagement is, therefore, a key part of our motivation. Other studies characterize DTcs as not only a simple technical system but as having the potential to be sophisticated socio-technical systems that integrate social, political, cultural and economic perspectives.

Communities can become more active in advising on and responding to city change and development plans. This helps to make citizens more engaged, which in turn leads to greater community resilience. Ye et al.'s (2022) research focuses on such goals. This kind of approach supports the development of a city that is more than just a physical urban environment; but instead a social-ecological system.

Consequent Research Focus

As indicated above, the opportunity for the public to express their will through a communication method of two-way dialogue and consultation with decision-makers can have a positive effect on urban planning and public policies. The essence of public participation is to coordinate diverse interests of different stakeholders to ensure the planning decisions and processes are fair, just, and open (Innes & Booher, 2007).

The research presented here therefore evaluates geolocated AR technologies interfacing with DTCs as a means to facilitate two-way dialogue. Below, we describe the establishment of an AR technology environment with the means to achieve this using current technological systems that can link citizen responses and feedback to the DTC dataset.

In 2022 the SCOPUS database was searched first for "digital twin", and then "city/cities/urban" then "public/citizen/people/social". This revealed that only 0.17% of papers addressed social, public and citizen issues related to digital twin at that time, underlining the gap that our work intended to help fill.

PROTOTYPE EXPERIMENTS

Establishing the performance requirements of the technologies was envisaged by the identification of typical tasks that a citizen would need to be able to accomplish using the AR-enabled device. The three particular tasks would be:

1. Make geolocated comments on an urban design proposal yet to be constructed
2. Insert feedback using 3D location marker on issues related to the existing urban infrastructure
3. Place a pre-designed artefact or object in a preferred location in the 3D environment

Figure 2 shows the conceptual diagram of how the system being developed is conceived.

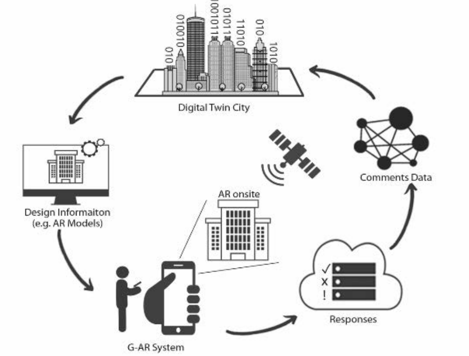

Figure 2
Conceptual diagram of the interaction allowing feedback from the G-AR device to the DTC model

The next sections illustrate how different issues have been addressed by evaluating the most appropriate G-AR component technologies to deliver the desired interaction and DTC communication capabilities.

Issue 1 - Geolocation

Simultaneous Localization and Mapping (SLAM) has become a fundamental element in underpinning recent AR technology. It is a technology used in vision technologies to interpret data from the physical three-dimensional environment in the form of points. In simple terms, SLAM refers to a set of methods to solve both the user position and associated 3D reconstruction simultaneously while a device or system is moving through the real environment

However, while SLAM provides an inherent tracking solution, it does not provide all of the answers as it does not have any reference to a known, real, global location (coordinate). So, additionally, SLAM has to be associated with Geolocation in order to unlock the global coordinate registration (location) needed to provide comprehensive mapping and tracking approaches. This is needed in order to develop a high-level and site-connected AR experience.

AR anchors are of three types: Local Anchors, Cloud Anchors, and Geospatial Anchors. Geospatial Anchors (aka: world anchors, location anchors) are based on geodetic latitude, longitude, and altitude, associated with GPS data. They provide precise location almost anywhere in the world. The user may place an anchor from a remote location as long as the app is connected to the internet and able to use the GPS. In recording the AR position, the setting can be as a Rooftop Anchors or Terrain Anchors.

For this study, the technology therefore uses Geospatial anchors to enable creation of the Geolocation-based AR experience for the user. This offers compelling advantages, enabling widespread accessibility and a global registration capability. Although the technology was still relatively new and under development early in the study has striven to integrate it to contribute to the potential applications for this technology.

Issue 2 – Interaction Device

With the potential of geolocation-based AR, current mobile devices are making complex urban information and services more understandable for the public and offer personalized user experience feedback. This unlocks the potential to create a sense of spatial smartness for the user that is connected to the digital twin framework.

There is a range of potential devices, including head-mounted displays and tablets, that could be employed for users to locate themselves in a real context with AR interaction capability. However, as noted, the emphasis is broad citizen interaction and universal access to technology. The mobile phone is therefore the primary interaction device envisaged in this project.

Modern mobile phones have vision sensor (cameras) for object recognition. In addition, tracking orientation, movement, and rotation using a combination of accelerometers and gyroscopes, allow mobile phone devices to determine orientation and movement in 3D space. Smartphones with depth cameras and associated AR development kits like ARKit and ARCore offer features like motion tracking, environmental understanding, light estimation, and depth perception. This makes possible competent AR experiences where virtual objects can be placed and provide visual interaction reasonably accurately with the real world. For these reasons the hand-held smartphone was considered the appropriate target device for the research described here.

Issue 3 – SDK choice

A Software Development Kit (SDK), is a collection of tools, libraries, and documentation to support the creation of applications for a specific platform or technology. AR SDKs, for instance, facilitate AR recognition, AR tracking and AR content rendering. In October 2023 we selected ten AR SDKs to make a comparative analysis of their features and appropriateness when applied to an urban smartness task.

Table 1
Comparison of SDKs

AR SDK	Item	Version	Platforms					Cross-platform ability	Type of licence			Device support				Targets recognition						SLAM (simultaneous localization and mapping)	Geo-location support	Extended support			
			Web/ SaaS	Android	iOS/ iPadOS	Windows	MacOS		Free licence	Commercial licence	Open source	Smart phone	Tablet	Desk computer	Smart glasses/ Headset	2D Image	3D Object	Multi-targets	Ground Plane	Area Targets	Cloud recognition			Unity	Unreal engine	Adobe Aero	Windows Mixed Reality
vuforia	Vuforia	9.8	●	●	●	●	○	●	●	●	x	●	●	●	●	●	●	●	●	●	●	●	●	●	●	x	○
ARKit	Apple ARkit	6.0	●	x	●	x	●	x	●	x	x	●	●	●	○	●	●	x	●	x	●	●	●	●	●	x	x
ARCore	Google ARCore	1.3	●	●	●	○	●	●	●	●	●	●	●	●	○	●	●	●	●	○	●	●	●	●	●	●	○
MRTK MIXED REALITY TOOLKIT	Windows Mixed Reality Toolkit	3.0	x	x	x	●	x	x	●	●	x	○	●	●	●	●	●	●	●	○	○	●	x	●	●	x	●
ARTOOLKIT	ARToolKit	5.4	●	●	●	●	●	●	●	●	●	●	●	●	●	●	x	●	●	x	x	●	x	●	●	x	●
wikitude	Wikitude	9.1	●	●	●	○	x	●	x	●	x	●	●	●	●	●	●	●	●	○	●	●	●	●	x	x	●
kudan	Kudan	1.3	x	●	●	○	x	●	●	●	x	●	●	x	x	●	●	●	●	x	x	●	x	●	x	x	x
EasyAR	Easy AR	2.6	●	●	●	●	●	●	●	●	x	●	●	●	○	●	x	●	●	x	x	x	x	●	x	x	x
XZIMG	XZIMG	3.0	●	●	●	●	x	●	●	●	x	●	●	●	○	●	●	○	●	x	x	x	x	●	x	x	x
MAXST	MAXST	6.0	x	●	●	●	●	●	●	●	x	●	●	●	●	●	●	●	●	x	x	●	x	●	x	x	x

The criteria used to make the comparative study were: platform breadth; cross-platform capability; types of licence and device support; target recognition capability; SLAM capability; geo-location support; extended tool support.

The results of the analysis of the ten SDKs are shown in Table 1. The solid circle indicates positive, the cross negative and o indicates partial meeting of requirements.

The comparative study revealed that Apple ARKit and Google ARCore had the strongest credentials base on their accessibility and inclusivity of their mobile platforms and devices due to their broad user base. At the time of implementation, Google Geospatial Creator became available within ARCore. This very useful development empowers developers by providing accessible tools and powerful features to create geolocation-based AR experiences that intertwine the digital and physical worlds.

Therefore, ARCore and its Geospatial Creator API was selected as the primary research tool for subsequent experiments.

Issue 4 – AR platform

An AR platform, is the environment used to create and develop AR applications, and provides tools, services or capabilities for developers to design, test, deploy and build their system. It acts as the framework tool for implementing AR functions, with components such as graphics, audio, physics, input, scripting, networking, user interface and so on.

Six popular AR platforms were compared based on platform support, cross-platform capability, licence type, programming language, device support, local and cloud database function, IDE compatibility (ability of a system to recognize and utilize storage devices), extended tool support and sharing capabilities. In addition, 5 key features were assembled for each platform to supplement the feature comparison (Table 2, below).

Table 2
AR platform comparison

Items		A-Frame	Unity	Unreal engine 5	Adobe Aero	Reality Composer (Incl.Pro)	Windows Mixed Reality
Platform support	Web/ Saas	●	●	○	X	X	X
	Android	X	●	●	○	X	X
	iOS (incl.iPadOS)	X	●	●	●	●	X
	Windows	X	●	●	●	X	●
	MacOS	X	●	●	●	●	X
Cross-platform ability		○	●	●	●	X	X
Type of licence	Free licence	●	●	●	●	●	●
	Commercial licence	X	●	●	●	●	●
	Open source	●	X	X	X	X	X
Programming language		JavaScript	C#/C++(runtime)	C++	Node.js	Swift	C#
Device support	Smart phone	●	●	●	●	●	○
	Tablet	●	●	●	●	●	●
	Desk computer	●	●	●	●	●	●
	Smart glasses/ Headset	●	●	●	●	●	●
Database	Local (on-device)	●	●	●	●	●	●
	Cloud (on-line)	○	●	○	●	●	●
IDE compatibility	Web	●	X	X	X	X	X
	Unity	●	●	X	○	X	●
	Android Studio	●	●	●	○	X	X
	Xcode	●	●	●	○	●	X
	Visual Studio	●	●	●	○	X	●
Extended tool support	Google ARcore	X	●	●	●	X	○
	Apple ARkit	X	●	●	●	●	X
	Windows Mixed Reality Toolkit	X	●	●	X	X	●
	Vuforia Tools	X	●	●	X	X	○
	Unity ARfoundation	X	●	X	X	X	●
Sharing abilities	Document (image, model, text, video,	●	●	●	●	●	●
	Quick Link	●	●	X	●	○	●
	Code (incl. QR code)	●	●	X	●	●	○
	Non App required	●	X	X	●	X	X
	Instant App (App Clip)	X	X	X	●	●	X
	Full App	X	●	●	●	●	●

This comparative analysis suggested that Unity and Adobe Aero should be prioritized as the best AR platforms for the subsequent experiment.

CAPABILITY TESTING

With the platform and SDK selected, the next stage was to implement the three functional capabilities prescribed in the 'Prototype Experiments' section above. The performance of the developed system is reported below with the results for each of the three major tasks summarised in tests 1, 2 and 3, respectively.

Reference to previous AR testing methodologies was instructive. For instance, Reinwald and Berger (2014) explored using AR for public participation in traffic planning through the "way2gether" project. This project involved field tests in Vienna with residents, comparing traditional and AR-based methods. Such early projects were somewhat limited by more cumbersome tablet devices with more limited capability than contemporary smartphones.

The current technologies have the potential to address the shortcomings identified in these early studies that can be summarised as:

- Improved geolocation accuracy and image stability
- Wider accessibility and engagement
- Enhanced interactivity and communication
- Better scalability and registration

For practical reasons we chose the area of the city adjacent to our university building for the testing. 20 people took part in this prototype testing. The site location had three important advantages:

- it made access for testing convenient
- a building next to the University building had been demolished and a replacement was planned so we could test obtaining user-feedback about a planned urban change
- it has a mix of building and landscape elements

Prototype capability test 1

The requirement here was the ability to make geolocated comments on an urban design proposal yet to be constructed. Figure 3 shows the site that has been cleared and there are proposals for buildings of different heights on the site. The site is outlined in red.

Figure 3
The vacant site

Figure 4 shows the QR code that is scanned to bring up the building digital twin on the mobile device on site. Once accepted (second image in Figure 4) the building appears in the AR scene (right hand image in Figure 4).

The AR view seen by the user on site is shown in Figure 4. The diagonal lines are not present in the real situation – they are phenomenon of the interference between the screen and the photographing device.

Initially, there were significant issues in enabling the remote communication to the mobile device. We started with simple geometric object location at the correct position. Once the communication issues were solved different mobile devices were found to be able to read the QR code and initiate the AR experience.

An interesting point is that in user testing of the AR environment for the 10-story building, for capability test 3, some test users tried to 'walk into' the AR building to see the inside. However, for practical reasons of data transmission only the external skin had been modelled. But it was reassuring that the users were fully engaged with the AR experience. This bodes well for more advanced application of the principles that will enable users to see and respond to multiple new design options.

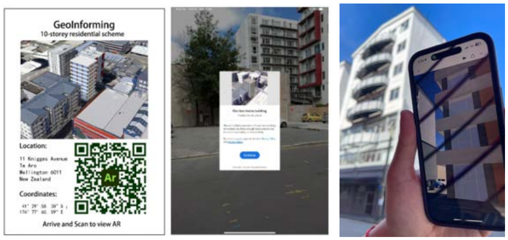

Figure 4 (opposite)
Initiating the geolocated AR view on site

Prototype capability test 2

This user test required the ability for the on-site user to insert feedback using a 3D location marker on issues related to the existing urban infrastructure. The test showed that with the technology combination derived from the comparative analysis above, markers of different types could be placed.

A problem or complaint is marked by an x in the twin model and a suggestion is recorded as an exclamation mark. A green tick indicates citizen approval of an intervention or change. As can be seen in Figure 5 comments were successfully placed using the AR system (screen shots in lower images) and the geolocation technology maps these to DTC environment correctly (upper image).

Figure 5
Markers left by G-AR user after leaving comments on site

Prototype capability test 3

The third type of task was to place a pre-designed artefact or object in a preferred the 3D environment. The test involved adding planting to a small urban park located just outside the university building (as shown in Figure 5).

A library of simple landscape elements can be called up for placing on the AR environment. Figure 6 shows the library of elements provided to the users. Like the markers shown in Figure 5 these elements are geolocated so the data on their coordinates and properties can be transmitted back to the main city digital twin model.

When the ‘editing scene’ function was initiated, the AR objects (such as the trees in this example) are initially anchored to the ground i.e. the X and Y axis (ground plane), but the library object can also be translated along Z axis to be elevated. But it was found that some users needed personal instruction on how to place objects in 3d space. Most other functions were intuitive but for those from a non-architectural background in particular, 3D manipulation generally proved more challenging. Most non-design testers just edited the AR models with their fingers on the touch screen (without axis assistance) so placement in these cases was relatively crude and approximate.

Figure 6
Library of landscape elements provided to AR users

By adjusting the heights and scales of these digital props and placing them within the digital twin model, the simple landscape design can be simulated by the AR users. The overall effect can then be assessed in the DTC environment.

Figure 7
G-AR view after objects have been placed on site by the user

EVALUATION

As illustrated in the observations and figures above, initial user testing showed that all three of the prescribed functions could be achieved with the developed system.

Despite the unexpected, annoying and exasperating technical issues that researchers in areas like this always face in getting the technologies to 'talk to each other' and to 'do what they are supposed to do', the SDK and AR platform combination arising from the comparative studies mentioned above (and summarised in Tables 1 and 2) proved capable of delivering the required specification demands to permit straightforward citizen feedback as shown in figures 2 to 7.

However, technological capability and on-site testing only establish that the technology *can* work, and *potentially* deliver the performance needed. What is appropriate now the successful framework and working prototype has been established is to test the usability of the proposed AR system. This involves testing against a logical and structured set of criteria. For this we are employing a comparative evaluation technique using IsoMetrics (version 2.01e). The work on evaluating the operation and performance using this method will be reported in a subsequent article.

CONCLUSIONS

The research described here reports on the development and testing of technological approaches to enable citizens to deliver feedback to government bodies and other stakeholders in a way that is geolocated and linked to the DTC representation. It does so through the medium of an AR environment, whilst the citizen is on site.

Evaluation of appropriate delivery tools and technologies indicated the most effective combination of current technologies to deliver citizen/public comment that can be linked to specific geolocated points in the twin. These have been tested in three critical use-cases and have operated successfully. The provides a promising foundation for more detailed testing and evaluation of the technique. The combination of tools and processes (workflow) is intended to be repeatable by other cities, giving them a citizen feedback system that is owned by the city and not a third party.

There are two major focus areas where detailed tests with a group of users are planned. In each case we will also evaluate the level of success in the dta being successfully transmitted to the DTC.

The first development is to enable accurate placement by all types of user, of objects in 3D space, or switching objects in 3D space. This functionality is needed to allow citizen response to a particular urban change proposal by either choosing from alternative design options or enabling citizens to place a designed building, street furniture or artefact in a preferred location.

The second is to expand citizen feedback interaction than that illustrate here would be desirable. Voice notes for instance placed using a more developed interface would be valuable.

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