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Integrating Photogrammetric 3D City Models and CityGML Data into Augmented Reality for Enhanced Urban Planning and Cadastre Management

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Abstract

In an era of rapid urbanization, three-dimensional (3D) city models have emerged as crucial tools for managing infrastructure, planning new developments, and maintaining accurate cadastral records. Recent advances in photogrammetry and geographic information systems (GIS) have allowed us to generate incredibly detailed representations of urban spaces. The General Directorate of Land Registry and Cadastre has played a pivotal role in creating 3D city models by capturing aerial imagery and converting it into CityGML-based solid and architectural models. Although CityGML offers a standardized framework for storing and sharing city data, its potential can be further magnified by integrating immersive technologies such as Augmented Reality (AR). This paper presents a mobile AR application, developed with Google’s ARCore, that displays CityGML-based building data at street level, allowing for real-time visualization and interaction. Our pipeline simplifies raw CityGML data, ensuring optimal rendering while preserving essential details. Through effective georeferencing and advanced pose estimation, these digital models are accurately overlaid on real-world scenes, enabling government agencies, urban planners, and cadastral managers to analyze and make informed decisions in situated places. Beyond planning and cadastre, this AR system could benefit broader fields such as environmental monitoring and public infrastructure management. We conclude by discussing future steps, including expanded data layers (e.g., utility networks) and performance optimizations for large-scale city models, thus highlighting the transformative role of AR in shaping next-generation urban environments.

1. Introduction

Cities around the world are undergoing rapid transformations: sprawling suburbs, high-rise clusters, and intricate transport networks are just a few manifestations of the rapid urbanization of today. As new roads and structures emerge, the demand for comprehensive 3D city models has skyrocketed. Planners rely on these models to visualize zoning changes, architects use them to gauge aesthetic impacts, and cadastral officials rely on them for accurate land registry data. Traditional methods of mapping and city management cannot always keep up with the complex and ever-changing urban environment, so more innovative approaches are needed.

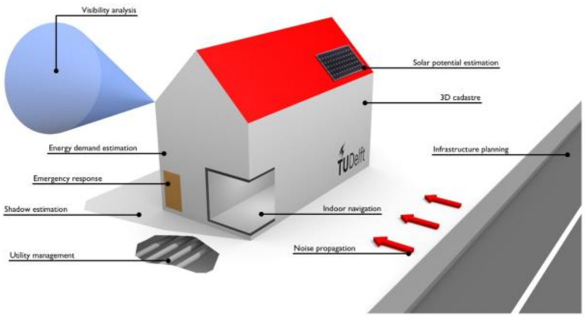

Figure 1. 3D City model applications (Biljecki et al., 2015b).

One promising technological framework is CityGML, an open data standard introduced by the Open Geospatial Consortium (OGC) (Groger et al., 2012). CityGML organizes and encodes 3D city data so that it is consistent, interoperable, and relatively easy to share across different platforms. However, the question remains: how do we make these rich, multilayered datasets truly accessible, especially to stakeholders who need them in the field? Augmented Reality (AR) provides an intuitive answer. Instead of confining 3D city models to static screens, AR technology overlays digital information on the physical world, creating immersive experiences that help users interpret complex spatial relationships right in front of them (Azuma, 1997).

This paper explores a novel integration of CityGML-based photogrammetric data into an AR environment. The General Directorate of Land Registry and Cadastre, with its mandate to manage national cadastral data, has produced detailed building models from aerial photogrammetry. We demonstrate how these models can be adapted for mobile AR visualization using Google’s ARCore. Our approach involves data simplification, georeferencing, and advanced pose estimation, each step specifically tuned for the real-time constraints of mobile devices. We also discuss how this approach enriches urban planning, cadastral management, and a variety of other fields that rely on accurate city models.

2. Related Work

Numerous researchers have investigated ways to integrate 3D urban models with immersive technologies. The potential of CityGML for large-scale projects is well documented, especially when combined with building information modeling (BIM) or advanced GIS workflows (Kolbe, 2009; Biljecki et al., 2015). However, practical implementations often face bottlenecks related to data size, rendering efficiency, and georeferencing accuracy. Traditional desktop applications, though powerful, may not offer the real-time interactive experience that AR promises (Dollner and Hagedorn, 2008).

Past efforts in AR for urban planning frequently revolved around specialized headsets or heavily instrumented setups (Piekarski and Thomas, 2003). While effective in certain cases, these solutions may not be practical for large-scale field deployments or for on-the-go inspectors and planners. In recent years, mobile AR platforms like ARCore and ARKit have expanded possibilities by equipping everyday smartphones with advanced motion tracking and scene detection features (Google, 2018).

This democratizes access to AR, enabling city officials to make quick assessments right on site.

Predescu et al. devised a geospatially driven gaming platform, yet they soon hit a snag during the implementation stage. They realized there were tons of different frameworks out there—some were commercial, others were still in an experimental phase—and this made things tricky. On top of that, they said real-world testing was no walk in the park, mostly because calibrating everything in a live environment can get complicated fast (Predescu et al., 2019).

Portales et al. introduced a humble, low-cost outdoor AR setup. Their approach relied on photogrammetry to produce 3D photo models, which were then blended into the real world. To run the prototype, users needed a head-mounted display (HMD), while sensors handled navigation. Their findings suggested the tool could serve a variety of use cases, and they also argued that this method might be cheaper than plain-old virtual modeling in some scenarios (Portalés et al., 2010).

Sanaeipoor et al. proposed an AR-based strategy focusing on place marking for urban projects. They claimed this technology could play a big part not only in design work but also in broader community engagement. Essentially, the authors saw AR as a means to get different stakeholders involved, ranging from the public arts folks to citizens just walking around the neighborhood (Sanaeipoor and Emami, 2020).

Latino et al. built an indoor AR app prototype aimed at helping stakeholders pitch and refine urban design ideas. Their system displayed 3D objects on flat surfaces, letting people visualize concepts in an immediate, tangible way. They tested it with a small group that was more or less tied to the development team—though they admit broader user evaluations would strengthen their findings (Latino et al., n.d.).

Cirulis et al. came up with yet another AR app geared toward architecture and city planning. They showed that having 3D data is kinda vital for AR, especially since 3D views help folks really grasp a city's layout, buildings, and overall design (Cirulis and Brigmanis, 2013).

Muthalif et al. went in-depth on subsurface utility visualization techniques, splitting them into four categories—X-ray, transparent, shadow, and topo views. They compared each one on factors like depth perception, how they obscure the real world, complexity, and parallax effects. Ultimately, they found no single visualization method ruled them all; the best choice depends on what users actually need and what they're trying to do (Muthalif et al., 2022).

Wang et al. tackled the challenge of positioning in AR apps, pointing out how tough it can be to constantly update dynamic scenes in real time. They proposed a quaternion-based method for visualizing both 2D and 3D vector data, and their results showed it could reliably handle the positioning task. Plus, it boosts accuracy for AR vector displays, which might be a game-changer for certain applications (Wang et al., 2022).

Keil et al. hopped on the bandwagon of creating virtual worlds using open geospatial data. They noticed web technologies are making it easier than ever to share information globally, and as more spatial data becomes widely available, new types of virtual applications keep popping up. Still, they acknowledged a hitch: not all game engines can read every geospatial file format. To fix that, they explained how to translate public data into formats these engines can actually understand (Keil et al., 2021).

Nevertheless, big challenges remain: CityGML datasets can be quite extensive, so data processing pipelines must optimize geometry before pushing it into real-time AR visualizations. Achieving precise alignment between digital and physical objects also depends on robust pose estimation and up-to-date georeferencing methods. The work we present here attempts to tackle these issues by offering a streamlined pipeline for generating AR-ready assets from CityGML data, focusing specifically on street-level interactions and decision-making processes.

3. Methodology

3.1 Data Acquisition and Preprocessing

The General Directorate of Land Registry and Cadastre operates aircraft equipped with high-resolution cameras to capture aerial images over urban centers. Using photogrammetric techniques, these images are processed into orthophotos and 3D models. The resulting 3D building information is encoded in CityGML format. This step ensures that each building's geometry, texture, and metadata (like building height or footprint) are stored in a standardized framework (Gröger et al., 2012).

Despite the comprehensiveness of these datasets, they often include an overwhelming level of detail—millions of polygons for dense urban areas. Rendering such data in a mobile AR application isn't trivial. Therefore, we adopt a multi-stage data simplification approach. Firstly, we reduce polygon counts by removing redundant or invisible surfaces. Secondly, we compress textures where possible, striking a balance between visual fidelity and performance. Finally, we reorganize the data into a more compact structure suitable for real-time rendering, such as OBJ format or an equivalent optimized 3D format.

Accurate georeferencing is the backbone of any AR application that aims to superimpose virtual objects on the real world. We use coordinate transformations from the national geodetic reference system to a global coordinate system, typically WGS84. Since mobile devices often rely on GPS, the vertical accuracy might be off by a meter or two. This discrepancy can lead to misalignments when overlaying the building model onto the physical scene.

To mitigate such issues, we employ an additional sensor fusion step. Alongside GPS data, we incorporate device IMU (Inertial Measurement Unit) readings to refine position and orientation estimates. In some scenarios, local or site-specific reference markers are placed to further improve accuracy. These markers, recognized via computer vision techniques, provide anchor points that help the system align the 3D models exactly where they're supposed to appear.

3.2 Mobile AR Development with ARCore

We built our mobile AR application using Google's ARCore SDK for Android (Google, 2018). ARCore primarily tracks the motion of the device using a technique known as visual-inertial odometry. Basically, it uses the phone's camera feed and sensor data to figure out how the device is moving in the real world.

After calibrating the coordinate systems, the application loads the simplified 3D building models seen in the figure 2. We place these models in an AR scene graph, associating each with a

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virtual anchor based on either GPS or marker-based references. As users move around, ARCore continuously updates the camera's real-world pose, allowing the on-screen models to remain accurately locked in space. This continuous monitoring is critical to ensure that 3D buildings do not "drift" out of alignment.

Figure 2. Integrated 3D building data into AR.

3.3 User Interaction and Interface Design

User interaction and iterface design describes the conceptual and visual design of the Android application's user interface (UI), as designed in Figma. The design was guided by the principles of minimalism, clarity, and strong focus on user-centered navigation. The overall goal was to ensure that both beginner and experienced users could smoothly transition between a 2D map interface and an augmented reality (AR) experience, thus facilitating spatial awareness and user engagement. Figure 2 provides an overview of the primary screens in the prototype. Splash Screen, Map Screen, Permission Screen, Main AR Screen, and Location Permission Prompt. All in all, the design idea has been taken from Google's sample AR application (are, n.d.).

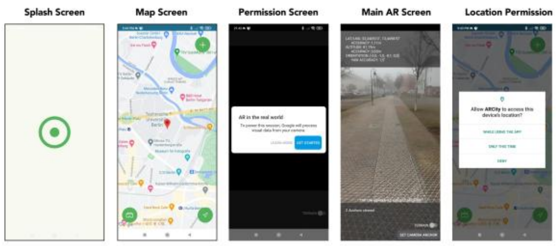

Figure 3. Overview of primary screens.

Upon launching the application, users are greeted with a Splash Screen featuring a simple circular graphic in the center of a neutral background. This visual element serves both as a recognizable brand mark and as a brief transition screen while the application is initialized. The minimalist design of the splash screen aims to reduce cognitive load and quickly orient the user to the core functionality of the application, spatial exploration through AR.

The screen's soft background color and bold circular logo were selected to convey a modern, technology-focused aesthetic while maintaining sufficient contrast for visual accessibility. Although not explicitly displayed in the mockup, the splash screen is designed to give immediate feedback on app initialization, ensuring the user that the system is loading necessary location and AR services.

After the splash screen, users move into the Map Screen, which serves as the central 2D reference for navigation and locationbased interactions. The map (powered by Google Maps) occupies the majority of the screen, providing an intuitive interface for the user to understand their surroundings. Two primary buttons float above the map in the lower corners;

- AR Mode Button, represented by a camera icon circled by a stylized "AR" label, this button initiates the transition to the AR camera feed. Its visually distinct iconography indicates a shift from 2D navigation to immersive 3D exploration. - Navigation/Compass Button, displayed as a compass icon, it controls basic map interactions, such as resetting the map's orientation and centering on the user's current location. Additional points of interest (e.g., universities, cafes, landmarks) are displayed as markers on the map. The decision to keep the interface uncluttered, with minimal overlapping UI elements, reflects an emphasis on clarity. Users can focus on either the immediate 2D environment or an eventual transition to AR without distraction.

Proper permissions are essential to enable AR features, as the app requires access to both the device's camera and accurate location data. Two sets of permission dialogs are presented at critical points in the user journey.

Camera Permission (AR Processing), labeled as "AR in the real world," this dialog explains how Google processes visual data from the user's camera to anchor virtual objects in the environment. The user is given the option to "Learn More" or "Get Started." Providing just-in-time information here fosters user trust by clearly stating how sensor data is used. Location Permission, A second dialog asks for geolocation access with multiple options: "While Using the App", "Only this Time", or "Deny." This approach follows modern Android guidelines to give users granular control over their data. Selecting 'While using the App' is crucial for real-time AR experiences that align virtual content with the physical surroundings of the user. (goo, n.d.) By separating camera permissions from location permissions, the application ensures that each request is contextualized. This approach reduces confusion regarding how visual and positional data are collected, used, and secured.

The Main AR Screen merges real-world camera views with spatial data overlays, delivering the core AR experience. Once permissions are granted, users see a live feed from their device camera, overlaid with sensor data such as latitude/longitude, altitude, orientation, and accuracy metrics. The top of the screen displays textual feedback: These dynamic updates inform the user of the underlying state of the sensors in their device, strengthening the real-time nature of the application.

User interaction is further enhanced through onscreen instructions;

"TAP ON SCREEN TO CREATE ANCHOR": Tapping on a point in the camera feed places a virtual anchor at that location, effectively linking the real world to 3D content or metadata.

"SET CAMERA ANCHOR": This button allows the user to establish a reference anchor that remains "locked" to the device's perspective, enabling more advanced AR visualization use-cases (e.g., measuring distances or overlaying building models).

Terrain Toggle: A simple switch near the bottom right corner labeled "Terrain" allows the user to overlay or hide an additional grid that aligns with the ground plane. This visual grid can help the user perceive AR content's correct scale and alignment within physical space. By combining textual sensor readouts, anchor-creation prompts, and toggles for optional map overlays, the AR Screen offers a balance of immediate, hands-on interactivity and technical transparency. The user can thus explore the real environment, placing anchors and receiving feedback in real time, without the UI becoming cluttered.

Throughout the interface, a consistent visual language has been maintained,
Color Scheme: Greens and neutral tones dominate the iconography and highlight elements, reflecting a modern, map-oriented brand identity while also ensuring strong contrast.

Icons and Labels: Rounded and minimalist icons, paired with concise labels, help users quickly grasp the meaning of each action (e.g., "Get Started," "Terrain," "Set Camera Anchor").

Adaptive Layouts: The design, as seen in Figma prototypes, is responsive to multiple device sizes. Floating action buttons (FABs) are positioned to remain reachable by the user's thumb, aligning with modern mobile usability standards.

Moreover, the transition between screens is deliberately streamlined. The user naturally progresses from the splash screen to the map view, from which they trigger camera and location permissions, culminating in the main AR experience. This flow keeps each segment of the interaction logically separated while retaining user context—ensuring minimal cognitive overhead when switching between 2D and AR environments.

4. Results

The prototypical Android application successfully demonstrated the integration of CityGML-based building data in an augmented reality (AR) environment at street-view level using a Xiaomi Redmi Note 8 Pro device. Figure 5 shows an example of the 3D rendering within the AR environment, where a small virtual building model appears superimposed on the live camera feed.

A key technical finding was that direct usage of CityGML or CityJSON data in the ARCore framework was not feasible, because ARCore only supports specific 3D file formats such as .obj, .fbx, and .psd (are, n.d.). Consequently, the CityGML data had to be converted to the .obj format for successful rendering in the application. Although the converted 3D building model is viewable in AR, its proper placement and scaling at the street-view level require advanced posing techniques, particularly with shader programming and visual scripting, to accurately anchor the object in real-world coordinates.

Another important outcome relates to user permissions for camera, storage, and location services. The developed application demonstrated that users are clearly prompted at runtime to grant these permissions, and the app ceases to function if any of these are denied. This approach ensures compliance with privacy guidelines and highlights the inherent dependence on camera and location data for meaningful AR experiences.

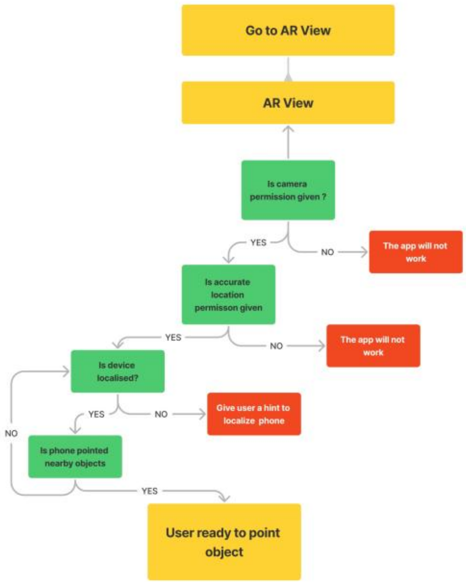

Figure 4. AR app workflow.

Regarding data conversion, initial attempts using the FME desktop application to process CityJSON data did not yield useful results. By contrast, converting CityGML to .obj provided a workable solution for integrating the 3D model in AR. As depicted in Figure 5, the depicted building is initially rendered at a relatively small scale due to its large real-world distance from the user's current position. As the user physically moves closer, the rendered 3D model appears larger. However, as noted, the current method does not perfectly resolve positioning issues, underscoring the need for more sophisticated techniques that better handle sensor fusion and object anchoring in the realworld environment.

Finally, testing the application proved challenging since the Google ARCore Geospatial API relies on external data from Google Street View to align virtual content with real-world locations. Full-featured trials required an outdoor setting, thereby making in-lab or office-based testing incomplete. Despite these constraints, the preliminary tests confirm the feasibility of integrating CityGML-based models in a geospatially anchored AR environment, setting the stage for further refinements in model conversion, positioning accuracy, and user interaction.

5. Discussion

Our experience integrating CityGML-based photogrammetric data into a mobile AR application underscores both the promise and perils of such a venture. On the one hand, the combination yields a powerful system for immersive city exploration and decision-making—allowing users to examine building models in a far more intuitive manner than flat maps or even standard 3D desktop viewers. On the other hand, performance constraints and alignment challenges demonstrate that robust, large-scale AR is still an evolving field.

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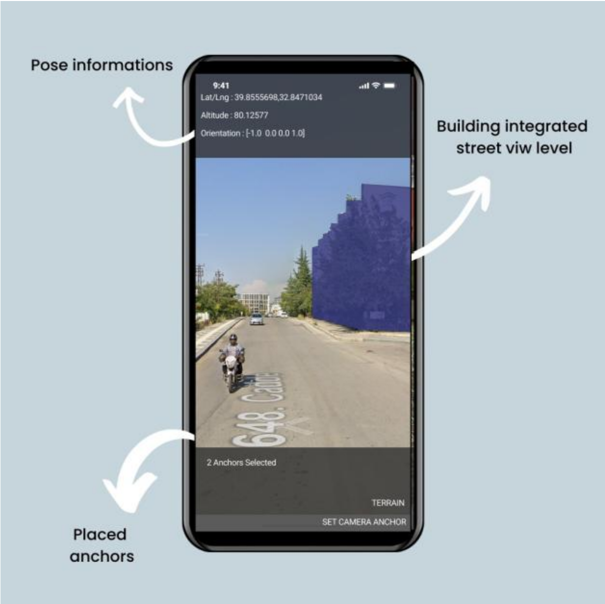

Figure 5. Integrated 3D building data into AR.

While planners might be thrilled about real-time building overlays, some conservationists could be wary of over-reliance on visual simulations that gloss over environmental factors. Similarly, city residents might worry about privacy implications if such AR tools become ubiquitous. Balancing these viewpoints requires transparent governance and clear regulations about data usage. Skeptics might argue that heavy dependence on mobile AR is risky because it’s prone to sensor errors and uneven device performance across different smartphone models. They could also note that the large volume of CityGML data would require robust cloud infrastructure, especially if entire city models are to be streamed. Our prototype partially addresses these concerns by implementing data simplification and offline caching, but more sophisticated architectures are definitely needed for city-scale rollouts.

Despite these concerns, the technology’s benefits are undeniable: immersive visualization can spur better collaboration among city officials and help local communities understand proposed changes in a tangible, street-level perspective. If carefully managed, AR integration of CityGML data can lead to more informed urban development, especially as we expand the technique to incorporate environmental data, utility networks, or even live traffic feeds.

6. Conclusion and Future Work

This paper presented a mobile AR application for visualizing photogrammetric CityGML-based building models from a street-level perspective. By simplifying 3D datasets and leveraging the capabilities of Google’s ARCore, we achieved interactive, real-time overlays that can aid urban planners, cadastral managers, and other stakeholders in on-site assessments. Our results suggest that AR-based visualization of city models can improve decision-making processes in numerous domains, including environmental monitoring, infrastructure development, and smart city initiatives.

In the future, several enhancements are on our radar. First, we plan to include more data layers—like underground utility lines and environmental parameters—so that users can get a holistic view of urban spaces. Second, we’re exploring machinelearning techniques to improve pose estimation in challenging conditions, such as areas with repetitive architectural features or poor lighting. Third, we aim to optimize our data pipeline further, perhaps using dynamic level-of-detail algorithms that adjust the model complexity based on the user’s distance from the object. Finally, larger pilot studies in multiple cities will help refine the system’s scalability and robustness, laying the groundwork for widespread adoption in the near future.

We conclude that AR, combined with standardized 3D data formats like CityGML, represents a transformative approach to visualizing and interacting with digital urban content. As cities continue to grow and evolve, such immersive tools can empower policymakers and local communities alike, fostering more transparent, efficient, and inclusive planning processes.

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