Fantastical reality: designing virtual urban space through extended reality

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Abstract

The rapid advancements in Extended Reality (XR) technologies and their integration into the urban design process bring the definition of 'space' and its production to the forefront, where a new type of designable space that accompanies, surrounds, and complements physical urban interventions emerges: the virtual space. XR technology has opened up new avenues for creating virtual content in urban contexts. However, despite the potential for XR to fundamentally alter how we create and experience urban environments, there is a lack of literature on how to use XR to create immersive and accurately placed virtual experiences that complement our physical urban realities.

This work aims to address this gap in the literature by exploring the potential of XR technology, specifically AR, for designing virtual urban space. The study follows a Research through Design approach (RtD), materializing findings through an experimental project in the form of a mixed-reality application that augments the city of Tampere, Finland. The developed application introduces virtual urban space as a space for cultural and artistic co-creation, offering the public a tool to reshape and envision their city through the lens of Augmented Reality (AR).

This work offers insight into the latest tools and software development kits (SDK) used to augment large-scale urban areas. It proposes a solution for accurately placing virtual content in urban environments, and presents considerations for designing virtual urban space, as well as current technology limitations and future research avenues.

Author keywords

Virtual Space; Urban Design; Extended Reality; Augmented Reality; Visual Positioning Systems

Introduction

In today's world, ever-evolving technologies have seemingly swept the globe, blurring the line between what is real and what is not. This sensitive interplay between the physical and the imaginary has touched upon many aspects of our everyday life and has, in some cases, formed a new framework for understanding the world around us; creating novel ways to experience ordinary things.

Recent technologies have made it possible for different realities to exist and merge with the one we live in and interact with. The term Extended Reality (XR), an umbrella term that comprises Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), but is not limited to these three, has come into existence and people are slowly escaping everyday life into this newly emerging form of reality that can be designed, adapted, and harnessed to improve the way we experience our surroundings (Liu et al., 2017).

XR technology has opened up new avenues for the creation of virtual content in urban contexts. However, despite the potential for XR technology to fundamentally alter how we create and experience urban environments, there is a lack of literature on how to use XR to create immersive and accurately placed virtual experiences that complement our physical urban realities.

This work aims to address this gap in the literature by exploring the potential of XR technology, specifically AR, for designing virtual urban space. The paper begins by reviewing the existing literature on XR technology and its use in urban design and envisioning future urban scenarios. It then presents a case study in Tampere, Finland that showcases the potential of using XR in designing virtual urban experiences while presenting the latest tools that facilitate this process. Finally, the paper discusses the opportunities XR technology offers and provides suggestions for further research in this area.

Background

The use of AR for Urban Design: Definitions and Justification

AR systems are those that allow real and virtual objects and information to coexist in the same space and provide real-time interaction. They allow the user to view the real world with overlaid virtual objects and enrich the user's experience and perception of reality with additional information. However, AR does not replace the real world as in the case of Virtual Reality (VR) (Redondo et al., 2017). According to Klopfer and Squire (2008), AR could be defined as "a situation in which a real-world context is dynamically overlaid with coherent location or context-sensitive virtual information" (p. 205). It is the synthesis of computer images in the real world (Zachary et al., 1997). And it can be identified by three basic features: 1) It combines real and virtual environments, 2) It is interactive in real-time, and 3) It provides accurate three-dimensional registration of real and virtual objects (Azuma,1997). Mobile

Augmented Reality (MAR) provides the aforementioned features without constraining the individual's location to a specially equipped area. It can be used anywhere, allowing the user to access AR experiences and add layers of information to any environment anytime through mobile devices (Höllerer and Feiner, 2004).

AR and VR share some similarities in terms of immersion, navigation, and interaction (Redondo et al., 2017). Unlike VR, which completely immerses the user in a virtual environment, AR allows users to experience the real world through a virtual overlay (Bower et al., 2014). It is important to highlight that the main goal of a VR system is using technology to replace rather than complement reality and create a new immersive environment, while the main goal of an AR system is to enhance reality by overlaying it with virtual content in a complimentary non-immersive way that enriches the user's perception of the real environment (Billinghurst et al., 2015).

In a discipline such as Urban Planning and Design, in which spatial and contextual information are core components of professional practice, Squire and Klopfer (2007) suggest that AR applications hold a particular promise and provide enormous potential for enhancing the design process due to their ability to connect academic content and practices with our physical, lived worlds. Potts et al. (2017) mention a shift and a direction toward the integration of AR in planning and designing public spaces in the physical world, and emphasize the possibility that urban planners will need to engage in both, the physical and the virtual placemaking process in the future.

Augmented Reality in Urban Design

The introduction of Augmented Reality applications into the architecture and urban design study and practice has provided a new channel of interaction with the built environment and produced a need for a new set of skills and a higher level of digital proficiency alongside traditional paper-based design and analysis skills to be developed in order to utilize these tools to their full potential (Indraprastha and Shinozaki, 2009).

Billinghurst et al. (2015) expand on the significance of augmented reality (AR) in the fields of architecture, urban planning, and urban design by pointing out that while 2D plans can show a building's layout in great detail, it would be challenging for the client to visualize the building through 2D drawings. Physical models, 3D renderings, and interactive flythroughs can therefore provide a solution to this problem, but they are scaled-down representations of the final space. These might not accurately portray the building's final image, including its final scale and placement within the urban context. The use of AR allows users to view full-sized 3D virtual models of future buildings placed in their intended contexts. (Calabrese and Baresi, 2017; Redondo et al., 2017). This allows AR to be utilized as a planning tool, placing different variations of the same building on-site and allowing for stakeholders' feedback, collaboration, and participation in the design process.

In addition to serving as a tool for visualizing future projects and urban development scenarios, Mesárošová et al. (2015) present an example of an application used in Urban Planning education called "Visionary Cities" created by AR Group Manusamo&Bzika. Through AR, the application provides the possibility to view and explore cities and concepts that were never built and remained as sketches, such as projects done by Archigram (A neo-futuristic avant-garde architectural group formed in the 1960s (Sadler, 2005)).

Envisioning Future Urban Scenarios Using XR

In today's world, there is a need for new urban visions that address pressing urban issues, concerns, and transformations such as overcrowding, social inequality, environmental degradation, climate change, urban gentrification, increased refugee influx, increased surveillance, technology and the smart city discourse in urban planning, etc. (Sevilla-Buitrago, 2013; Leorke, 2020). Augmented, virtual, and mixed reality can be powerful and effective tools that support the conceptualization, visualization, and communication of imagined urban futures.

A study by Shawash and Marji (2020) explores the potential of Mobile Augmented Reality (MAR) technologies as a tool for public engagement with ecologically sustainable urban regeneration projects. They present two urban development scenarios for envisioning a greener version of the city of Amman, Jordan by virtually reintroducing the city's enclosed and dried-up water stream and proposing sustainable water management solutions through an interactive table-top AR model of the site. The study envisions "what if" scenarios of the city's only water stream, and uses AR to present this vision to the public, engaging them in the dialogue of imagining a greener, more sustainable future for their city.

A study by Thibault et al. (2021) proposes a fictional city, one that utilizes augmented city technologies "to produce creative and playful spaces for citizen–urban interventions" and places the people in the center of the place-making process. The proposed model uses the city as a resource for activities and initiatives that allow the people to shape their environment and envision shareable alternate scenarios, strengthening their right to be represented and to use the city. Residents can explore, create, and modify the city's virtual augmentations, and develop a sense of ownership over its public spaces (Thibault et al., 2021). The authors suggest that the required technologies that allow us to interact in unprecedented ways with the urban environment seem to be available and what is needed is to combine them in the right way.

The Challenges of World-scale AR

Calabrese and Baresi (2017) explore placing urban design proposals and student projects in an outdoor urban context in the city of Milan. They attempt to enhance the accuracy of placing virtual design interventions by detecting specific 3D models and using beacons (small, wireless transmitters that use Bluetooth technology to send signals to other nearby devices). However, the proposed solution adds additional complexity to the average user and requires the detected 3D object to be always in view.

Rohil and Ashok (2022) explore the use of building information modeling (BIM) software along with AR visualization to present two types of urban planning scenarios: the creation of new structures and the recreation of existing designs. They offer a more recent overview of the workflow and possible tools that can be used to integrate AR into architecture and urban design. Nevertheless, the presented results showcase a proposed design floating in space rather than being placed in its designated location and in the correct orientation and scale, and little is discussed on the potential of utilizing visual positioning systems (VPS) for enhancing placement accuracy and designing compelling virtual experiences.

Although many studies attempted to explore and use AR in the context of urban design and to augment urban space, very few address the accurate placement of virtual content in urban areas. Whether the AR layer presented proposed buildings, urban development proposals, image/video overlays, creative 3D models, etc., its placement in the real world has faced challenges due to GPS and localization inaccuracy (Blum et al., 2013; Calabrese and Baresi, 2017; Redondo et al., 2017; Rohil and Ashok, 2022). The introduction of AR elements in urban contexts, whether marker-based AR (detecting a certain image or QR code through a device's camera to place virtual content) or marker-less AR (using a device's camera to detect vertical and/or horizontal planes or 3D objects in the surrounding environment to place virtual elements) or even location-based AR (utilizing specific location coordinates to load virtual content in specific areas), the placed virtual content in a large outdoor setting would shift, jitter, disappear, get misplaced, and move with the user's movement as they attempt to explore it.

Moreover, manual placement of large-scale virtual elements using a device's input (e.g., touch screen), such as buildings, urban furniture covering an entire street, indoor virtual content, etc. is inefficient and poses additional challenges and limitations to the users, especially if they are new to the technology and are not aware of the designer's decisions regarding optimal placement.

Another important consideration when designing XR experiences is the user's point of view (POV), which holds substantial implications for the design, perception, and overall efficacy of the immersive environment.

Utilizing a first-person perspective, or world-scale AR, enables users to perceive and engage with the urban environment from a human-scaled perspective, resulting in a more immersive experience. In urban XR experiences, the first-person perspective facilitates a more profound understanding of spatial relationships, architectural scale, and the experiential qualities of the built environment. This can offer insightful information on how people will use the built environment and how it will affect their perception of the area. This POV, however, can be constrained in terms of the quantity of data that can be concurrently displayed on the screen, which can make it harder to assess the design as a whole.

Alternatively, users are able to observe the complete area from a bird's eye view when using the third person perspective, such as in Tabletop AR, which offers a more objective and thorough view of the urban environment. the third-person perspective positions the user as an external observer, detached from the immediate context, and often overlooking the virtual environment from an elevated or distanced vantage point. This POV provides users with an overarching view of the urban fabric, enabling a more comprehensive understanding of the spatial structure, urban patterns, and connectivity. However, it may be less realistic and not as effective when expressing how people interact with the built environment compared to the first person POV and may reduce the sense of immersion and personal agency within the XR environment.

It's critical to consider which POV to use depending on the nature of the project and the desired feedback. For instance, first person POV might be more effective for assessing the pedestrian experience of a brand-new public space, while third person POV could be used for assessing the effects of a major development on the local urban fabric. The POV can also affect the usability and accessibility of XR technology for various users, the level of depth and accuracy necessary in designing the experiences, and the techniques used for evaluation and feedback.

The case study discussed in the following sections presents an example of utilizing XR technologies in co-creating virtual urban space. It explains the used tools and solutions for creating accurately placed, immersive virtual content in the city.

Methodology

This study draws on a comprehensive review of literature in the fields of XR technology, urban design and planning, as well as Human-Computer Interaction (HCI) and follows a Research through Design approach (RtD); "an approach to conducting scholarly research that employs the methods, practices, and processes of design practice with the intention of generating new knowledge." (Zimmerman and Forlizzi, 2014, p. 167). This work materializes insights and knowledge through an experimental project in the form of a mixed-reality application that augments the city of Tampere, Finland. The developed application introduces virtual urban space as a space for cultural and artistic co-creation, offering the public a tool to reshape and envision their city through the lens of augmented and mixed reality. To investigate the use of XR technology in designing virtual urban space, the presented case study involved observing and documenting the design process, the performance of the mixed reality application prototype, as well as users' reactions to it.

The ideation and development of the application prototype were done in the following steps:

1) **Literature search on the use of XR in urban contexts as well as current challenges and technology limitations.**
2) Identification of the latest open-source and available tools for augmenting city-scale spaces.
3) Schematic analysis of Tampere city's layout and optimal locations for introducing virtual content.
4) Informal interviews with local Finnish artists regarding the need for exhibiting their art in public spaces as virtual content.
5) Collection and design of context-specific virtual content to be placed in selected locations in the city.
6) Development and testing of the mixed reality application prototype using MAR and AR glasses.

This work aims to offer insight into the latest technologies used to augment large-scale urban areas, considerations for designing virtual urban space, as well as current limitations and future research avenues.

Case Study: the Tampere xRT Project

Tampere, Finland's third-largest city, is regarded as a hub for business, technology, and culture. The city is renowned for its cutting-edge technological research and advancements as well as its vibrant cultural scene, which features a wide range of museums, theaters, and festivals.

This project offers individuals access to alternative and novel viewpoints of the city that can enhance their daily lives by leveraging Tampere's diverse cultural experiences and the potential of XR.

By allowing users to shape their own virtual urban surroundings, the Tampere xRT project examines the idea of placemaking through XR and presents the city as an open exhibition. It offers a sustainable and accessible platform where local and international artists, cultural venues, and the public can share their visions of the city, by showcasing their art in virtual urban space. The project explores how the public realm of Tampere can be co-created with XR through the collaboration of artists and the public.

Problem and proposed solution

For providing immersive and accurate AR experiences in outdoor urban settings, the project aimed to tackle the AR placement-accuracy challenges and offer an experience that can run on mobile devices as well as AR glasses. Different locations around the city were selected, those included a neighborhood park (Figure 1), a pedestrian bridge in the city center, and a landmark in Tampere's city center to explore the effectiveness of the AR solution in a 1) green setting, 2) an active pedestrian route, and 3) a distinguishable building and plaza. The design of virtual content in urban space not only provides a playful and interactive experience but can also enrich the public's perception of the city. This offers opportunities for visualizing future urban developments, historical information, and even fictional and fantastical scenarios as a form of speculative design that can widen users' imagination and allow them to rethink their surroundings.

Figure 1. Left: user viewing virtual content in a park using AR glasses, Right: the user's view through the AR glasses showing virtual 3D model in the park

Developing Urban XR Experiences: Tools and Technicalities

The project utilizes Visual Positioning Systems (VPS) to identify the users' location and accurately place the virtual content in physical space. The process begins with mapping specific locations in the city by using photographs, creating a spatial map and point clouds of the location, and extracting feature points that can be then detected, ensuring accurate localization (finding the position and orientation) and placement of the virtual content. For this process, the "Immersal" software development kit (SDK) was used, and the created maps of the scanned locations were then inserted into "Unity", a game development engine, for designing and determining the location of the virtual content that will augment the physical space (Figure 2).

The Immersal SDK facilitates the process of creating location-aware spatial environments using any mobile device, offering fast visual positioning with low system overhead. It enables devices to precisely locate and orient the users' view in the physical world, allowing accurate placement of persistent virtual content in their surroundings.

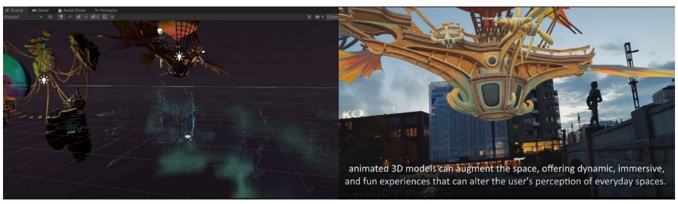

Figure 2. Left: Unity's work space showing the point clouds of the bridge and the placement of virtual content, Right: mobile screenshot of the bridge area through the AR app, showing the placed virtual content in its physical location.

In addition to using the Immersal SDK, Google's Geospatial API recently released in 2022 was also used to add 3D virtual elements in locations that were not priorly scanned using Immersal's tools. Google's Geospatial API allows developers to use Google's pre-scanned data and feature points used in Google Street View AR to accurately place virtual content in any place in the world. However, the capabilities offered by Immersal's mapping tools by scanning specific building facades offer element-specific augmentation. This means that virtual content can be placed on certain windows, walls, ornamentation, roofs, etc.

Nevertheless, the localization of the devices faced some challenges after sunset, since the spatial maps were created from images captured during the daytime. This was resolved by mapping the environment at different times of the day to capture the context in different lighting conditions and ensure correct AR placement and environment detection in all settings.

The projects' results were shared with the public, as well as Tampere's municipality and multiple cultural venues including the Tampere theatre, Tampere Art Museum, and Tampere City Library, which all presented a positive attitude toward the introduction of XR in the city and the proposed platform.

Conclusion

XR technology is rapidly developing and the intersection between the real and the virtual is increasing at a quick pace. This study discussed the use of XR in urban contexts, the design of virtual urban space, and the tools available today to facilitate this process. Following an RtD approach, this work presented a case study that explores the latest software development kits for creating accurately placed AR content in large urban settings. Moreover, the study offered a possible solution for a challenge frequently faced while exploring the usability of AR in outdoor contexts.

XR offers great potential for the fields of architecture, urban planning, and design, and allows us to envision and experience future urban scenarios in real-time on-site and in full scale.

For architects, urban designers, planners, and other professionals involved in shaping the built environment, XR technology opens up new design options, promotes teamwork, streamlines decision-making, and boosts productivity as it can be connected with other technologies like Building Information Modeling (BIM), Geographic Information System (GIS), and Internet of Things (IoT). Additionally, by focusing on more immersive and interactive experiences rather than 2D drawings and models, XR has the potential to revolutionize the design discipline, resulting in new processes, tools, and techniques for design as well as new ways for practitioners and stakeholders to collaborate and communicate with one another.

However, the current state of XR technology, specifically MAR is limited by the utilized hardware and requires large processing power, which can result in low refresh rates, device overheating, and a lack of immersion for users with older devices. Moreover, further research is needed on designing good quality and context-specific virtual content for augmenting urban spaces without overpopulating them and creating visual noise for the users. Several social and regulatory challenges are also presented when implementing XR technologies in the urban realm, those include but are not limited to accessibility, safety, privacy, impact on the built environment, as well as legal and regulatory issues, which could be explored in future research.

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