

# Integrating Immersive Technology into Micro-Scale Spatial Design for Urban Villages

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17–32

Rapid urbanisation in China has led to urban villages, presenting challenges in spatial governance and renewal. Advanced digital and parametric methodologies can extend beyond traditional building-focused strategies to address public space vitality and resident demand issues. However, their effectiveness in capturing and responding to intricate spaces and individual needs within urban villages remains underexplored. This study investigates how mixed reality (MR) in experiential design systems can revitalise urban villages. We review existing literature and design projects using digital tools in the survey, analysis, and design phases of urban village regeneration. We then propose a design framework that leverages immersive technology to revitalise public spaces. Using Shenzhen's Baishizhou as a case site, the research focuses on four types of highly utilised public spaces from the perspective of migrant renters. Integrating MR technology, this multi-port framework effectively bridges the gap inherent in existing digital tools, thereby enhancing designer productivity.

#urban villages

#urban regeneration

#sustainable redevelopment

#immersive technology

## Introduction

In recent decades, China has undergone rapid urbanisation, marked by extensive urban sprawl and significant migration from rural to urban areas (Liu et al. 2010). This phenomenon has led to the emergence of informal settlements known as urban villages, which are particularly prevalent in major cities, such as Guangzhou, Shenzhen, and Beijing (Gao et al. 2020). These urban villages are often viewed as supplements to formal affordable housing, providing essential living spaces for migrants lacking local *hukou* (Hao and Geertman 2012). As urbanisation intensifies, these settlements face myriad challenges, including high density, limited greenery, antiquated infrastructure and inadequate security.

Despite their apparent disorder, urban villages demonstrate resilient self-organisation (Lian and Hu 2020). The scope of conventional architectural interventions is often limited to individual buildings and overlooks intricate urban issues that encompass the broader urban interface, public space vitality, residents' demands and microclimatic considerations. Digital methodologies, particularly immersive technology, are acknowledged as an efficient approach to the multifaceted nature of these challenges. Yet, how can they serve as efficacious tools for addressing the manifold challenges presented in the revitalisation of urban villages?

This study aims to investigate the transformative potential of mixed reality (MR) in experiential design systems to rejuvenate these neighbourhoods. Through a comprehensive literature review, the existing academic work, design plans and real-world projects that have employed digital methodologies in urban village regeneration efforts are synthesised. While these applications have achieved their design objectives, there is a notable gap in research focusing on microscale spaces, particularly on enhancing public spaces for migrant renters from the perspective of daily

life. Consequently, Baishizhou Village in Shenzhen was selected as the focal point of the research and design of this study. By integrating AR technology, this research simulates the effects of microscale design on residents' lives, thereby illustrating the potential impact of AR-enhanced microscale design in urban village spaces.

## Literature Review

Over the past decade, immersive technology has undergone a significant transformation, propelled by the rapid advancement of technology and the digital age. Diverse immersive approaches have been integrated throughout the entire process of urban design. This section describes how a new study on digital urban design adds value to the existing literature, providing a path for rethinking regeneration strategies to improve microscale spaces in urban villages for residents.

## Immersive Technology

Immersive technology encompasses a range of technologies, including augmented reality (AR), virtual reality (VR), mixed reality (MR) and extended reality (XR). MR technology, in particular, integrates AR and VR to create a model for human-computer interaction in the real world. The application of VR technology, primarily within the fields of aviation, medicine and the military, dates back to the 1970s when Myron Krueger pioneered the fusion of virtual images with real human shadows in the same video (Krueger 1977). This technique and its subsequent developments have found widespread use in the rapid generation of as-built scenes through photogrammetry and laser scanning techniques (Cummings and Bailenson 2016). Advancements in hardware technology led to the development of numerous commercial AR head-mounted displays in the early 21st century. These devices support image technology and incorporate scene scanning capabilities, enabling the rapid virtual modelling of

real-world scenes through the integration of light detection and ranging (LIDAR) or colour cameras within headsets. These technological advancements have significantly facilitated the adoption of immersive devices within the architectural industry, aiding architects in acquiring site information in complex environments (Stals and Caldas 2022). Furthermore, most MR equipment supports gesture recognition technology, allowing for effective interaction through the use of joysticks and gesture recognition.

During the preliminary phases of the design process, the architect must conduct a comprehensive site analysis, which includes precise measurements and the development of a detailed virtual model. AR headset can rapidly generate a site model, enabling designers to gain remote insight into the spatial structure of the design site. Mesh models, constructed through the point cloud, are both storable and exportable, facilitating editing through commonly used design software. This real-time modelling technique offers the advantages of rapid modelling speed and user friendliness. It partially addresses the issue of model bias stemming from incomplete data in the traditional city information model, particularly in areas such as urban villages, which are characterised by highly complex and rapidly changing spatial structures due to the self-organisation of spaces by the community. Real-time modelling effectively captures the spatial information of sites. Furthermore, support for point cloud-format input allows VR headsets to be used in conjunction with high-accuracy sensors to obtain more precise models and additional information, such as materials (Zhang, Deng, et al. 2021). This approach has been applied widely in the field of architectural heritage for the collection of structural data, yielding favourable results (Banfi, Brumana, et al. 2019; Banfi, Previtali, et al. 2019).

In conjunction with robust interaction systems and multi-platform outputs, the utilisation of immersive technologies offers a promising

approach for effecting modifications, facilitating decision-making and eliciting feedback on design solutions (Avella and Schilleci 2020). Gesture recognition systems enable users to interact with information through actions such as tapping, dragging and pinching and benefit from low learning costs and high efficiency while also being customisable through the development platform. By leveraging the advantages of parametric modelling, designers can affect real-time design changes within the current environment.

In the realm of building construction, immersive technologies have been employed to coordinate work across various departments, particularly in conjunction with building information modelling, to effectively bridge the gap between the construction site and design drawings (Tran 2019). The compatibility of interactive development platforms with other mobile devices (e.g. game development platforms such as Unity) and other official tools allows for seamless data flow across platforms, enabling designers to gather user evaluations and experiences more effectively. These interoperable design platforms are frequently integrated with meta-universes and have garnered positive feedback regarding public participation in design. For instance, the NEOS VR social VR platform, which offers an immersive virtual game set in Lisbon city centre, encourages user participation in urban planning processes (Gebrian et al. 2021). Additionally, immersive interactive platforms have proven effective in community planning and in raising residents' awareness of their neighbourhoods (Romo 2021).

As immersive technologies continue to advance and become more accessible, their potential to reshape urban environments becomes increasingly evident. However, there remains a significant gap in understanding the specific benefits these technologies can bring to cities, particularly in terms of how they alter our interactions with the urban landscape (Parker 2021).

## Application of Immersive Technology in Urban Design

Urban design is inherently a visual discipline, requiring visualisation tools to inform public decision-making (Zhang, Zeng, et al. 2021). This process of public participation in urban design can be conceptualised as a collaborative endeavour wherein stakeholders, such as planners, politicians, citizens and other relevant parties, contribute diverse perspectives. Achieving mutual consent among all participants necessitates the use of various interfaces that facilitate mutual consent (Ben-Joseph et al. 2001). However, traditional urban design tools are confined mainly to 2D representations, which often lack intuitive engagement and fail to fully capture the complexity of the spatial environment. Furthermore, communication gaps between stakeholders persist, particularly due to the absence of timely updates, real-time feedback mechanisms and immediate communication channels (Moine 2017).

Immersive technologies have been introduced in urban spaces in innovative ways. A notable example is the global phenomenon of Pokémon GO, which encourages people to engage physically with urban spaces (Parker 2021). Extensive research has focused on the intersection of virtual and physical spaces, exploring areas such as augmented deliberation (Gordon and Manosevitch 2011), the luminous planning table (Broll et al. 2003), remote collaboration (Lee et al. 2016) and MR tools in urban planning projects (Ben-Joseph et al. 2001). These initiatives exemplify the potential of immersive technologies to enhance the urban design process by providing robust support for site recognition, issue identification and design refinement.

Immersive technologies offer distinct advantages throughout the urban design process, which can be categorised into three key phases: (1) surveying, (2) analysis and (3) participatory design.

### Surveying

Immersive technologies significantly enhance data acquisition and modelling processes, enabling the rapid and efficient collection of planning data. A notable example is the CityViewAR application in New Zealand, which was developed to provide geographic information about the city of Christchurch, which was devastated by major earthquakes in 2010 and 2011. This application offers detailed data on destroyed buildings and historical sites impacted by earthquakes (Lee et al. 2012).

### Analysis

Immersive technologies facilitate the seamless integration of multidimensional image data and human-computer interaction by overlaying virtual information onto physical environments. This integration not only enhances the accessibility of environmental data but also intensifies the sense of immersion for designers through the use of MR devices. As a result, designers gain a more nuanced understanding of the external environment and the rationality underlying their designs (Cummings and Bailenson 2016). By modelling spatial dynamics, preserving unique characteristics and preventing design uniformity, immersive technologies offer significant support in addressing complex spatial and social challenges. Consequently, they provide designers with greater control over their work during the analysis and design stages.

### Participatory Design

The rapid advancement of immersive technologies, coupled with the growing public desire to engage in the future of urban environments, has created valuable opportunities for more inclusive participation in the urban (re)design process. Immersive technologies introduce interactive interfaces that enhance public involvement in shaping the

spaces they inhabit or visit. In participatory design, these technologies allow for greater flexibility by adjusting parameters according to diverse stakeholder needs; thus, alternative planning schemes enhance the planning and design processes. Augmented deliberation – that is, real-time community engagement supported by interactive virtual models of proposed developments – has been shown to cultivate long-term commitment from both public and private stakeholders (Foth et al. 2018). Participants can provide feedback on design proposals by drawing, modifying or manipulating sections of 3D models as well as offering live commentary in the virtual environment while engaging in discussions with planners and fellow participants. Several neighbourhood revitalisation projects have successfully employed immersive technologies to collect residents' opinions and user feedback on design solutions, often in the form of gamified platforms that capture public input (Abdelhameed 2009; Behrouz 2024).

### **Potential of Immersive Technology in Urban Village Regeneration**

While immersive technologies have been explored extensively and have led to notable advancements in urban planning and design (Hajrasouliha 2024), their application in microscale, high-density and complex spaces, such as urban village regeneration, is an emerging field.

Urban villages, originally rural settlements with longstanding land ownership rights, are now encircled by and destined to become incorporated into new urban developments (Liu and Wong 2018; Liu et al. 2018). As a prevalent form of informal settlement in Chinese cities, these villages house millions of migrants who lack tenancy security and are largely regarded as vulnerable and marginal groups by scholars, local governments and developers. The inexpensive, substandard housing constructed by farmers in these villages to accommo-

date migrant workers is tolerated as a transitional measure to support high GDP growth through low-cost migrant entrepreneurship and labour (Zhang 2001). However, as urban development progresses, municipal governments inevitably move to formalise and regulate informality to achieve a modern city image and higher property returns (Liu and Wong 2018; Liu et al. 2018). Taking Shenzhen as an example, by 2017, there were 482 programmes related to urban villages, constituting 48% of the total volume of urban renewal programmes. When these villages are demolished, migrant residents will be displaced.

Recent studies have acknowledged and highlighted the value of urban villages and their migrant residents in urban development, advocating for the preservation of these areas through comprehensive improvement strategies (Liu et al. 2018; Zhang and Ye 2022). However, past demolition of and comprehensive improvement initiatives for urban villages have focused predominantly on visual order and failed to address the spatial and social issues within preserved urban villages, raising a debate for several reasons. First, urban villages exhibit greater spatial and activity complexity than general urban areas, thereby often rendering conventional spatial design methods inadequate for addressing specific challenges. Second, the demolition–reconstruction approach lacks micro-renewal practices, particularly those that consider the daily lives of urban village residents (Ling and Yang 2023; Xia and Song 2015). In addition, the daily needs and rights of migrant tenants during urban village redevelopment have yet to be fully recognised (Liu et al. 2018; Xia and Song 2015). Despite being the primary inhabitants of urban villages, migrant renters remain largely excluded from decision-making processes and are often treated as 'invisible' by key stakeholders (Liu et al. 2018). As such, it is essential that micro-scale interventions align with the daily needs of migrant renters, thereby preserving both the functional integrity and social vitality of urban villages during regeneration.

The recent application of digital tools in urban village regeneration, though still emerging with limited case studies, highlights the significant advantages of such tools. For example, Xu and Wang (2014) innovatively used ink diffusion on paper to simulate pedestrian flow, creating a dynamic model for urban functions and crowd movement. Lian and Hu (2020) quantified key parameters of spatial growth within urban villages and employed a Depth-First Search (DFS) algorithm to simulate their evolution. The resulting parametric model preserves the underlying spatial logic and order of urban village evolution, while simultaneously satisfying baseline regulatory requirements for housing. Parametric design in urban village renovation offers solutions that align with residents' needs and stakeholders' interests. In Shenzhen, the RUM platform, developed by Relational Urbanism and Arup in collaboration with Shenzhen University and local NGOs, mediates between maintaining affordable housing and profitable developments, providing financial and spatial quality insights (Llabres and Rico 2016).

While digital tools have introduced a novel approach to urban village regeneration, there remains a significant gap in the research and application of methods that address the specific daily needs of migrant residents within the unique context of urban villages. Existing approaches require advanced technical expertise, thereby presenting challenges in early-stage design work and posing barriers to public participation. Furthermore, urban village environments in China are characterised by smaller spatial scales and greater complexity compared to their foreign counterparts. Little is known about how immersive technology could benefit the regeneration of these specific areas. Therefore, this study aims to assist designers in the early stages of a programme by integrating immersive technology tools to swiftly gather information and demonstrate their designs' impact as well as modify design schemes through simple gesture interaction to better align with the urban village environment.

## Methodology

The research was carried out in Shenzhen, China, where five emblematic locations within an urban village were chosen as design scenarios. Designers utilised existing street data as a basis to develop five small-scale spatial designs aimed at improving residents' convenience through their integration. They simulated their design schemes using AR devices and superimposed virtual design models onto the actual urban village space through onsite environmental scanning. Finally, they made modifications to the model in real time to align it with the actual space, using an interactive system.

### Reasons for Selecting Baishizhou Village as the Case

Baishizhou Village is located in the eastern part of Nanshan District, Shenzhen. The original area of Baishizhou is divided into northern and southern sections by Shennan Avenue (Figure 1). The northern section, comprising Shangbaishi, Xiabaishi, Tangtou and Xintang villages, is currently undergoing demolition and reconstruction, leaving only the southern section's Baishizhou Village remaining. This village, on the south side of Shennan Avenue, contrasts sharply with its surroundings due to its high-density built environment, substandard housing and ageing infrastructure. Although it offers a diverse range of commercial services, Baishizhou Village's public spaces are limited.

Baishizhou Village was selected as the case for this study for several reasons. First, Baishizhou is situated in the inner city, where land values are higher and the expansion activities of local villagers have progressively reduced the availability of public spaces within the village. Therefore, it fails to meet the daily needs of residents. Second, with the northern section of Baishizhou undergoing demolition and reconstruction, a significant influx of tenants from this area has relocated to Baishizhou Village,

intensifying both the overcrowding and already limited availability of public spaces within the village.

### Model Processing and Data Streaming

During the design phase, the designers conducted site analysis using an online geospatial database. Subsequently, rapid modelling was performed using SketchUp. The exported 3D mesh model was then imported into Rhino for surface optimisation. In Rhino3D, the model underwent refinement to minimise the number of subdivisions without altering its shape or size. This optimisation process aimed to reduce rendering load during real-time rendering and ensure smooth performance on AR head-mounted devices. Once the model had been processed, it was streamed in real time using Fologram, a Rhino plugin that facilitates streaming between a computer and AR devices (Figure 2).

After establishing the streaming environment, HoloLens was chosen as the immersive device due to its superior field of view compared to other interactive devices, which allows users to maintain clear visibility of their surroundings, even while wearing the device. Additionally, HoloLens is capable of real-time environmental scanning and can transmit spatial point cloud models back to the computer. Given the spatial variability of urban villages, initial design outputs often exhibit a certain degree of misalignment with actual sites. This makes the point cloud model crucial for accurate model positioning. Designers manually adjusted the relative position between the design model and the site's point cloud data to determine the most appropriate design boundaries. Finally, these adjustments and onsite observations were documented for subsequent analysis.

## Results

### Analysing Public Spaces based on Users' Daily Demands

The expansion and building activities of local villagers have progressively encroached upon public spaces and green areas within urban villages, resulting in chaotic and overcrowded environments. The spatial organisation of Baishizhou has evolved into a network of narrow, linear streets and alleys that lacks the public spaces necessary to facilitate social interactions, such as conversations and leisurely gatherings. Additionally, as well as being limited, the public space environment is sub-standard, and there is a significant lack of facilities that support neighbouring activities.

Based on the fieldwork, the public spaces in Baishizhou Village can be categorised into three types: street and alley spaces (including spaces in front of shops on the main street and alleys connected to the main street), interstitial spaces and plaza spaces. The space in front of shops refers to the area between the red line of the main street and the buildings, which varies in scale and therefore accommodates different activities. Larger spaces can function as activity plazas and green areas, providing residents with opportunities for exercise, social interaction and relaxation and serving as outdoor commercial spaces. Smaller areas typically serve as entrance platforms for shops and can be used as resting spaces. Interstitial spaces, located between buildings and structures without occupying major roads or plaza areas, are primarily formed by elements such as building staircases, transverse walls and gable walls.

Due to limited public spaces, the street and alley spaces in Baishizhou Village serve as vital areas for residents' activities. These spaces are the primary venues for outdoor activities, such as resting, conversing, playing chess and card games and children's play. Several problems are prevalent in these

spaces. First, the sanitation conditions are poor, largely due to waste generated by food retail (meat and vegetables) and restaurants. Second, the main street lacks adequate resting spaces. Although vehicular access is restricted at the entrance, with the street primarily catering to pedestrians, the presence of parked delivery motorcycles occupies part of the space, further reducing the availability of resting facilities and diminishing the comfort of walking and leisure activities. Third, given the narrow width of the alleys (approximately 1–3 metres), the encroachment of miscellaneous items, private stools and parked vehicles creates a congested environment, limiting the space available for walking and leisure activities.

Plaza spaces within Baishizhou Village are notably constrained by the area's high building density, resulting in minimal per capita space for activities. In addition, these public spaces are characterised by a singular function and a simplistic layout, which significantly restricts the potential for diverse social activities. The limited, monotonous and uninspiring nature of these public spaces fails to meet the residents' demand for a variety of recreational functions, thereby diminishing these areas' effectiveness in supporting a vibrant community life. As for interstitial spaces, such as alleyways adjacent to homes and under external staircases, they are often cluttered with private items. This not only inconveniences residents but also significantly detracts from the cleanliness and overall appearance of the community's public spaces. These spaces fail to realise their potential utility and contribute little to enhancing residents' quality of life.

In summary, the observations of residents' daily demands revealed the following issues with the public spaces in Baishizhou Village: (1) street and alley spaces lack sufficient resting and parking facilities, and their functions are overly simplistic; (2) plaza spaces are similarly limited in functionality; and (3) interstitial spaces remain underutilised.

This study proposes an optimisation strategy for public spaces based on 'street and alley spaces + interstitial spaces + plaza spaces'. The approach focuses on enhancing micro-space quality by promoting the multifunctional use of space, supplementing service facilities, creating public spaces and developing green landscapes aimed at improving the overall living environment.

### Strategies for Micro-Scale Space Regeneration

Based on the analysis of Baishizhou Village, we identified five key plots characterised by high pedestrian traffic and strong connectivity and selected them as the design areas for this research. Block A encompasses the spaces in front of shops on the main commercial street, while Block B accommodates the gaps between the buildings and structures. Block C is connected to Block B, with both located in close proximity to the commercial street of Block A. Block C represents a transverse alley space, while Block D is an enclosed plaza space surrounded by residential buildings. Block D connects to Block A via Block C. In terms of the overall condition of these five blocks, there is single-function usage, prevalent informal activities, high potential for increased utilisation and strong connectivity between spaces, as depicted in Figure 3.

Given the limited public spaces within urban villages, this proposal emphasises functional integration. The redesign of Block A maximises the buffer spaces between streets and shop entrances by incorporating foldable, reversible and modular wooden structures that provide residents and shopkeepers with multifunctional facilities for resting, socialising, dining and transporting goods.

In Block B, the existing promotional walls and the gaps formed between buildings are utilised to install small architectural features. These features

maintain the promotional function while adding greenery, and with reversible wooden boards, they can double as seating or bicycle parking, satisfying residents' current demands.

In Block C, foldable seating, clothes racks and bike racks are integrated into the building façades without obstructing pedestrian pathways. The clothes racks can be flipped to serve as bike racks, ensuring that the street space is used efficiently throughout the day – for example, seating and clothes drying during the day and bike parking at night, with racks and seating folded away when not in use.

Finally, Block D is transformed into an outdoor domestic activity space for residents. The renovated plaza now includes additional greenery, meeting residents' current needs for clothes drying while also providing resting areas for parents and play areas for children.

### **Design Presentation through Immersive Technology**

Figure 4 illustrates the results of using AR technology to overlay digital models onto physical spaces. During this process, the design underwent secondary optimisation to better adapt to the site, which primarily involved modifications to both the design's form and placement (Figure 4). For example, in Block A, originally connected chairs were reconfigured into a segmented arrangement to better align with the dynamic spatial flow and accommodate various needs, such as dining and circulation. In Blocks B and C, frequent site changes and the presence of non-architectural structures posed challenges for real-time spatial scanning. To accurately reproduce the physical environment, critical spatial elements, such as wall positions and floor heights, had to be manually adjusted. Additionally, during the model import process, certain elements were repositioned to better align with their intended functionality, such as a bicycle station.

In Zone D, a lack of detailed information about ground elevation in the existing open-space data caused difficulties due to the combination of large spatial areas and uneven terrain. Real-time adjusted images were overlaid with the original design images at the same site locations, allowing for a clear visualisation of the adjustments made using AR technology (Figure 5).

Overall, the contact points between the models and physical environments were recalibrated using elevation data obtained from the scanned point cloud model. Designers seamlessly navigated the integration of virtual models with the real-world environment, particularly in areas where discrepancies existed between photographs, satellite imagery and the actual site conditions. Most designs across the four zones were modified to accommodate the site's unique characteristics, effectively embedding the intended design concepts into the spatial context.

### **Conclusion**

In the context of urban village design, immersive systems can effectively address the limitations of existing digital tools in terms of design presentation and information interaction. Utilising AR equipment for field space scanning, such as on White Stone Island, facilitates enhanced communication and presentation by dynamically conveying information and prompts between the computer and the designer's cognitive processes within the AR environment. This allows designers to experience the design and its site compatibility immersively, thereby increasing their control over the design process.

For complex and confined spaces in particular, such as urban villages, immersive systems can present site uncertainties, such as uneven terrain and accumulated debris, in real time. This real-time presentation narrows the gap between the designer and the onsite construction, thereby

enhancing the design's effectiveness. The future design process has significant potential for model interactivity, and the ease of interaction and efficiency of gesture recognition systems can substantially extend the design process to the community. A decentralised design platform that aggregates input from local residents could be developed, thereby facilitating connections among designers, builders and local residents and offering considerable outreach potential.

Despite the promising advantages of immersive technology, there remains substantial room for improvement in its scanning accuracy and display quality, particularly for small, irregular spaces that still depend on manual positioning and modelling. This issue could be mitigated by integrating higher-precision sensors. Overall, the combination of digital design technology and immersive technology has significant potential for application in the unique urban spaces of urban villages.

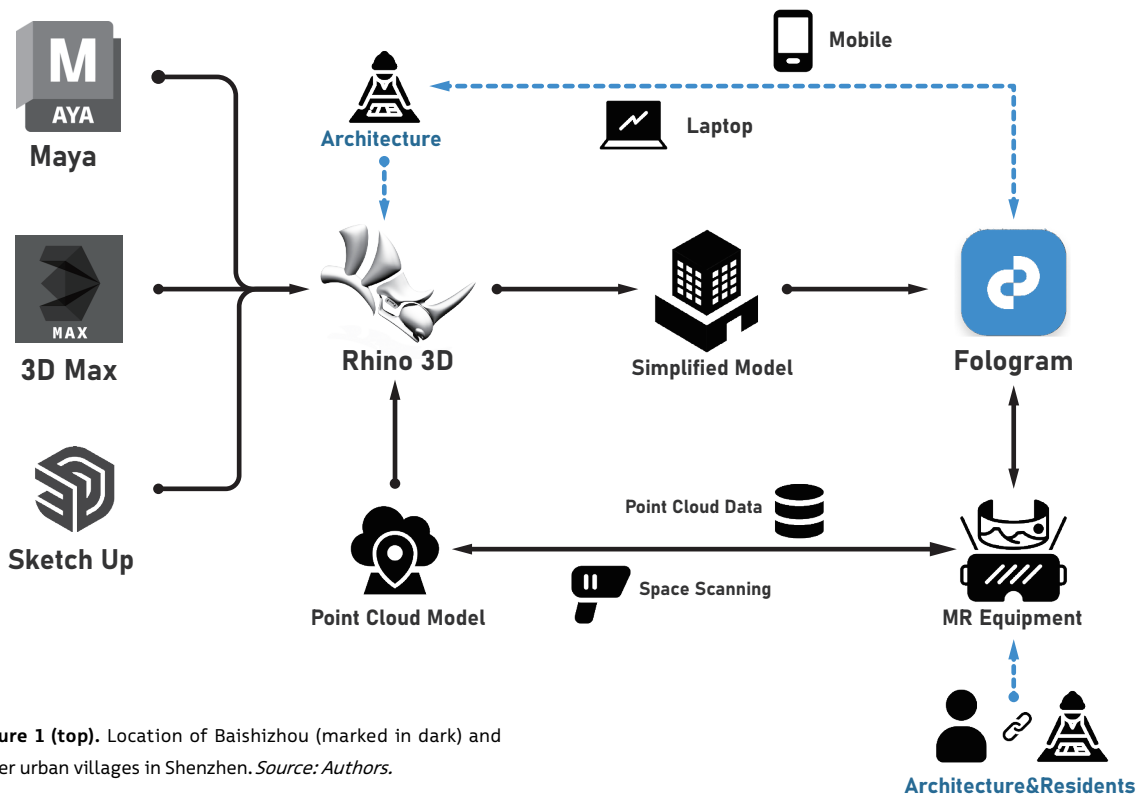
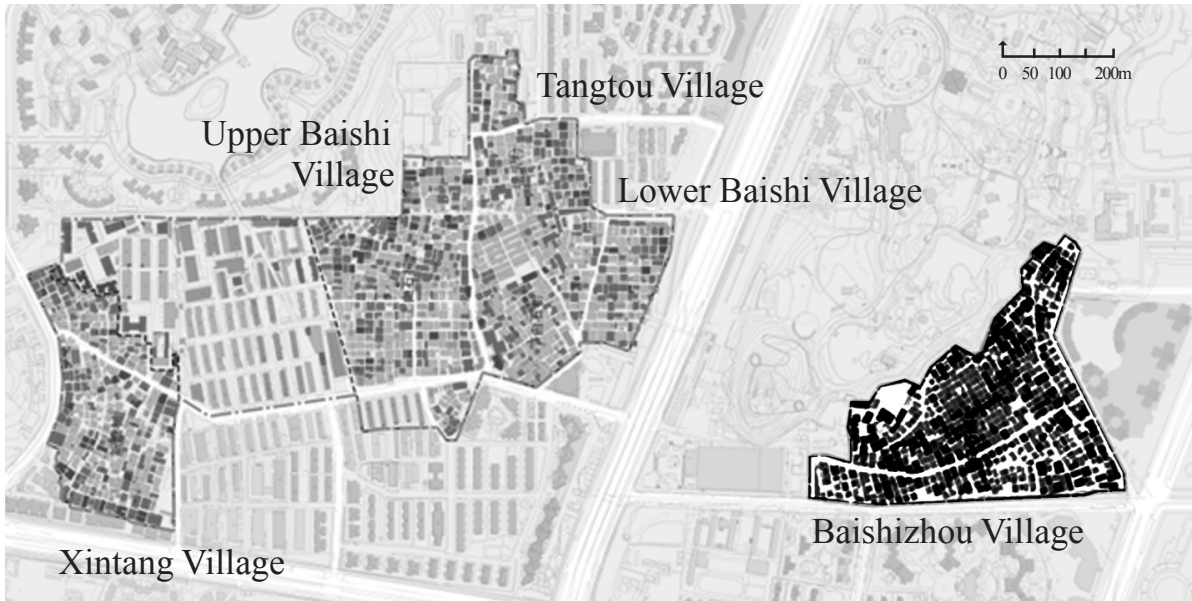
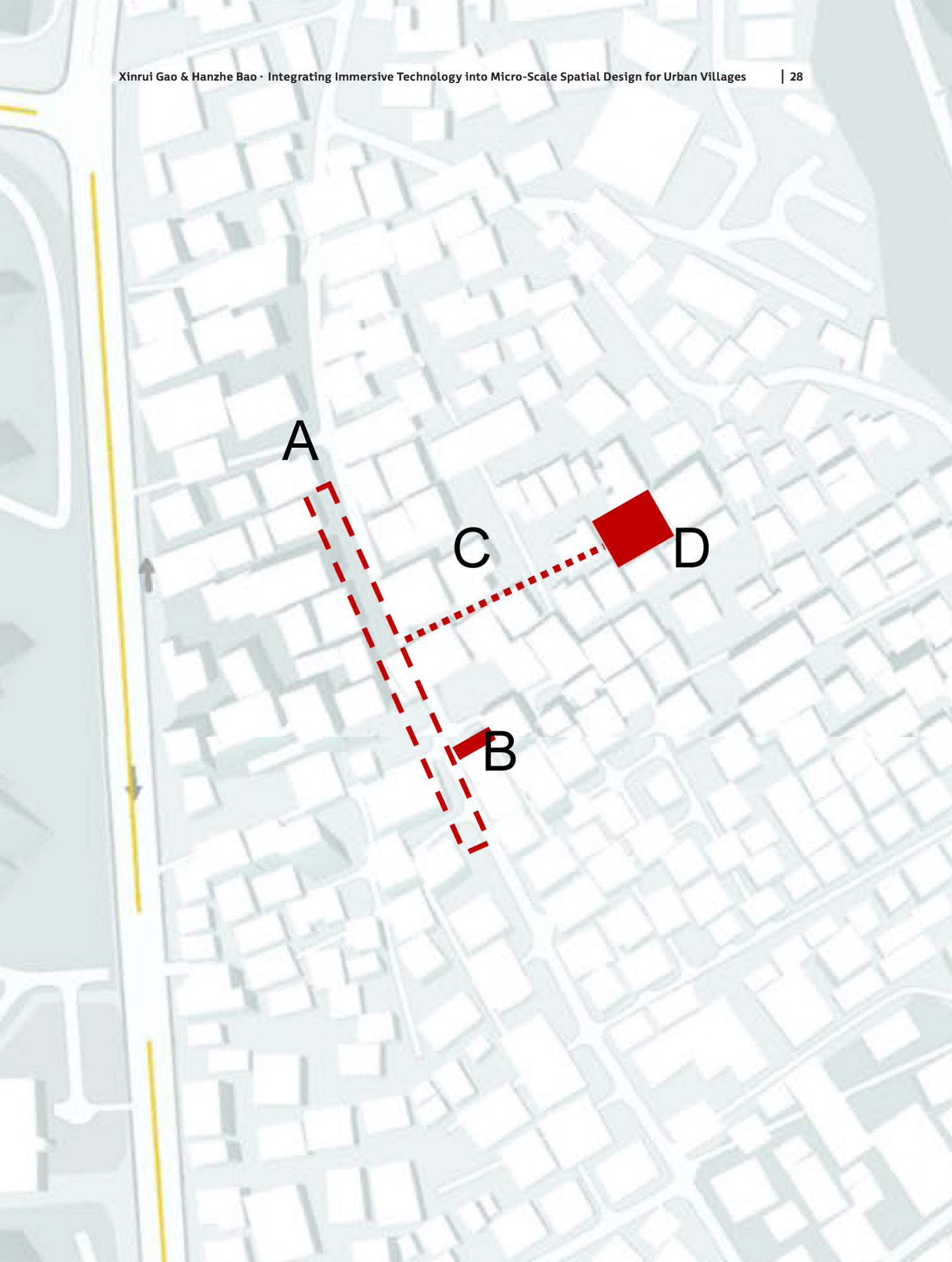


Figure 1 (top). Location of Baishizhou (marked in dark) and other urban villages in Shenzhen. Source: Authors.

Figure 2 (bottom). Workflow of collaborative modeling and design using MR technology. Source: Authors.

Figure 3 (opposite page). Four key design test areas (A, B, C, D) in Baishizhou area. Source: Authors.



A

C

D

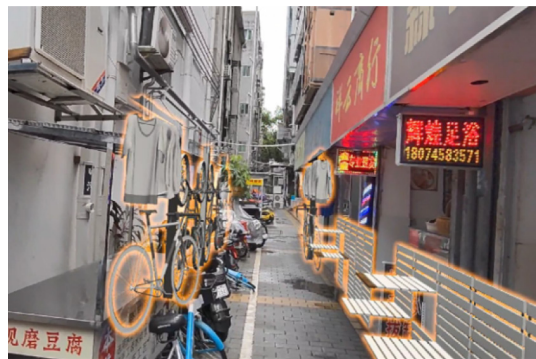
B



Block A



Block B



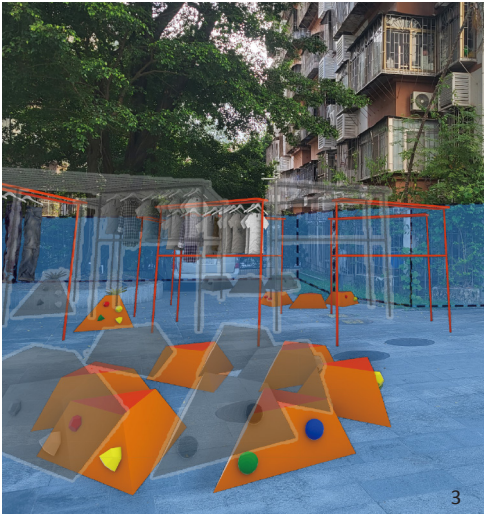
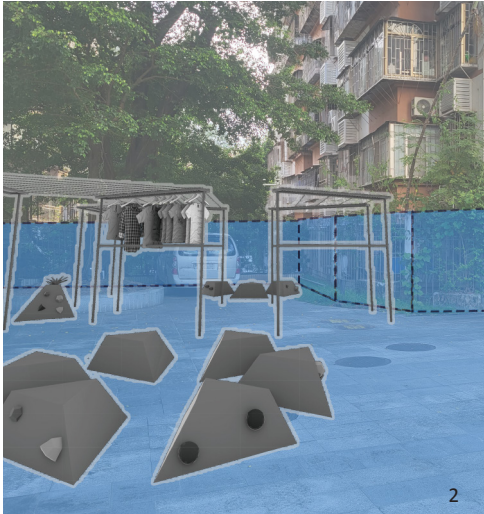
Block C



Block D

**Figure 4.** Digital models overlaid onto all blocks..

*Source: Authors.*



**Figure 5.** Onsite adjustment using alternative reality technology. *Source: Authors.*

1. Scan the environment to distinguish between the floor and walls.
2. Place a simplified virtual model in the scene.
3. Adjust the design based on the real-world context.
4. View the design results on a mobile or MR device.



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## Bio

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