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Inspecting Pond Fabric Using Unmanned Aerial Vehicle-Assisted Modeling, Smartphone Augmented Reality, and a Gaming Engine

Naai-Jung Shih *, Yun-Ting Tasi, Yi-Ting Qiu and Ting-Wei Hsu

Department of Architecture, National Taiwan University of Science and Technology, 43, Section 4, Keelung Road, Taipei 106, Taiwan; troycar306@gmail.com (Y.-T.T.); chooi0215@gmail.com (Y.-T.Q.); m11113011@mail.ntust.edu.tw (T.-W.H.)
* Correspondence: shihnj@mail.ntust.edu.tw; Tel.: +886-02-273-76-718

Abstract: Historical farm ponds have been designed, maintained, and established as heritage sites or cultural landscapes. Has their gradually evolving function resulted in changes to the landscape influenced by their degenerated nature and the new urban fabric? This study aimed to assess the interaction between urban fabrics and eight farm ponds in Taoyuan by determining the demolition ratio of ponds subject to the transit-oriented development (TOD) of infrastructure and to evaluate land cover using historical maps, unmanned aerial vehicle (UAV)-assisted 3D modeling, smartphone augmented reality (AR), and a gaming engine to inspect and compare well-developed or reactivated ponds and peripheries. A 46% reduction in pond area around Daxi Interchange was an important indicator of degeneration in the opposite direction to TOD-based instrumentation. Three-dimensional skyline analysis enabled us to create an urban context matrix to be used in the simulations. Nearly 55 paired AR comparisons were made with 100 AR cloud-accessed models from the Augment® platform, and we produced a customized interface to align ponds with landmark construction or other ponds using Unreal Engine®. Smartphone AR is a valuable tool for situated comparisons and was used to conduct analyses across nine categories, from buildings and infrastructure to the intensity and stage of development. The gaming engine handled large point models with high detail and was supported by a customized blueprint. We found that 3D virtual dynamics highlighted the evolving interstitial space and role substitution of the agricultural fabric. This combination of heterogeneous platforms provides a practical method of preserving heritage and enables conflict resolution through policy and TOD instrumentation.

Keywords: hydrogeography heritage; cultural landscape; unmanned aerial vehicle (UAV); point cloud; augmented reality (AR); gaming; Unreal Engine (UE); transit-oriented development (TOD); urban fabric; geographic information system (GIS)

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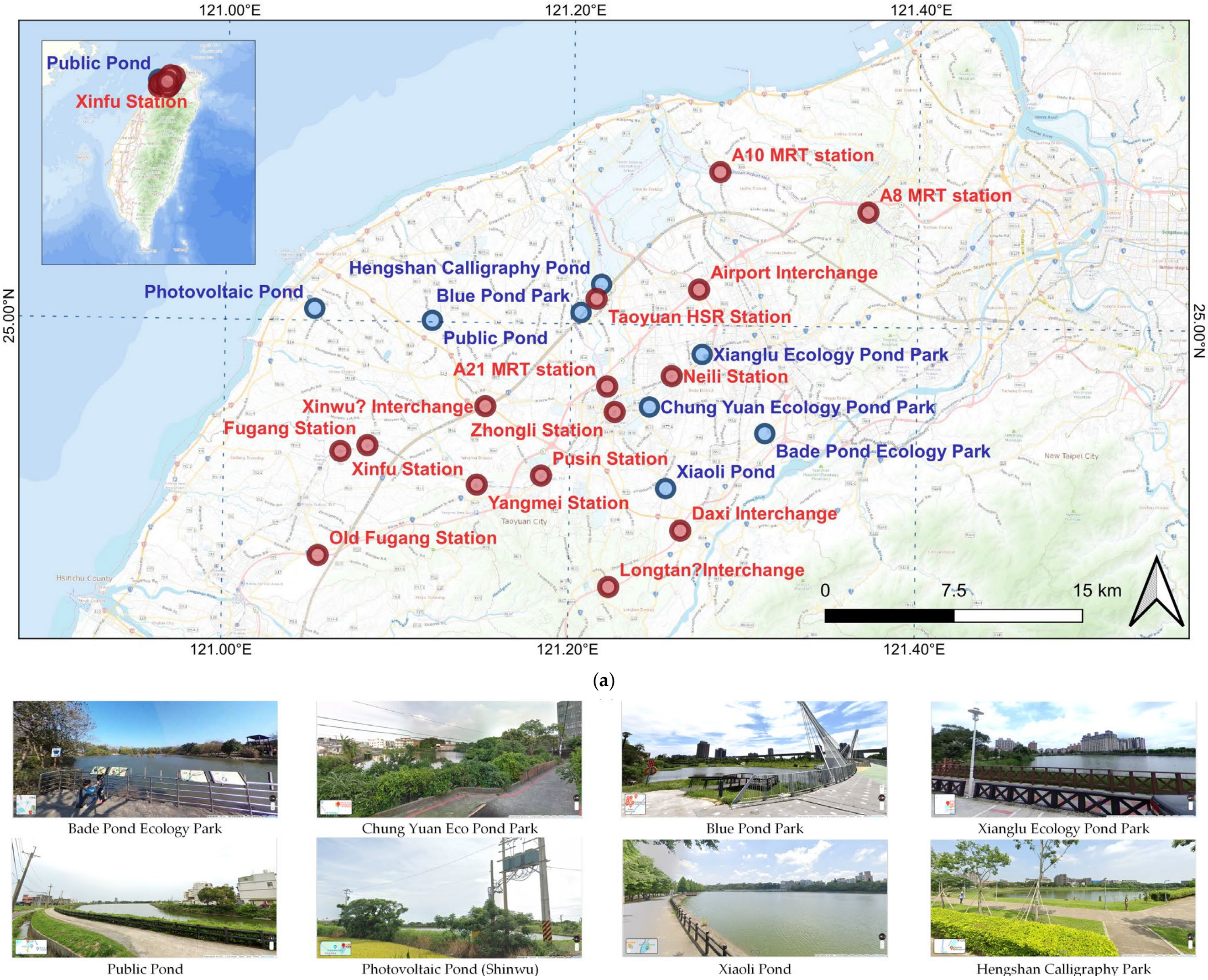
1. Introduction

The evolution of humans throughout history is closely connected to global and local hydrogeography. "Hydrogeography", as a branch of "hydrography", studies the distribution of water bodies and their impact on the environment and human society. In addition to generally being used for studying the physical environment, water bodies have mutually evolved with and have an influence on peripheral urban fabrics. Unfortunately, water bodies are also part of the land, which can become obsolete or be leveled for construction purposes. Farm ponds and peripheral areas are modified by urban reform or renewal for public infrastructure as a strategy of transit-oriented development (TOD) for promoting long-term sustainable development alongside public transport [1]. In addition to being a critical resource for human life, what can a water body provide other than playing a role in the landscape, tourism, irrigation, or transportation? Since ponds have become an important part of local cultural landscapes, human interaction deserves investigation.

This study aimed to assess the interaction between urban fabrics and eight farm ponds in Taoyuan (Figure 1) from two perspectives: (1) assessment of the demolition ratio of ponds subject to the TOD of infrastructure; and (2) evaluation of the land cover using UAV modeling, smartphone AR, and a gaming engine to compare well-developed or reactivated ponds and their peripheries.



(**a**)

(**b**)

Figure 1. The scope of this study: (**a**) map of ponds (in blue) and infrastructure (in red) (EPSG: 3857, WGS 84/pseudo-Mercator and EPSG: 32651, WGS 84/UTM zone 51N); (**b**) local pond scenes of Bade Pond Ecology Park [2], Chung Yuan Eco Pond Park [3], Blue Pond Park [4], Xianglu Ecology Pond Park [5], Public Pond [6], Photovoltaic Pond (Shinwu) [7], Xiaoli Pond [8], and Hengshan Calligraphy Park [9] from Google Street View®.

2. Related Studies

The shortage of land required for new construction and infrastructure has redefined the interrelationship between old irrigation systems and urban fabrics. In order to investigate the historical development of ponds, a detailed assessment of the development of land and building types should be conducted. Urban fabrics create a complicated maze of tangible and intangible contexts. People have created an extensive tangible network of infrastructure, buildings, and urban forms around water [10]. Land can be regarded as an engine for regional growth in terms of tourism, services, and infrastructure [11], and the transition of land use can exemplify the complexity of urbanization [12–15] over a period of 100 years [16].

Urban resilience is closely related to water resilience and describes the establishment of an activation plan for infrastructure that enables the economic improvement of a landscape or a system of ponds. Policymaking and design work help to develop sustainable futures for cities, landscapes, and water bodies [10]. Sustainable development goals (SDGs) have been developed in order to connect water and heritage for improved management in the future [17]. Resilience can be planned in order to fulfill specific purposes rather than gradually transforming irrigation canals into ditches or drainage systems as part of a sewer system [18]. With the use of original designs, the inherent function of ponds can be applied to flood control, pisciculture, or tourism in urban landscapes.

Water bodies evolve similarly to buildings and are subject to the spatio-temporal transformation of land. Water management has extended to lakes, from a broader perspective, to understand the social environment in relation to sustainability [19], provide cultural opportunities [20], fit into a wider cultural context [21], and understand the active role played by public waterscapes in the cultural and political aspects of collective memory and social change [22]. Water control and management have been fundamental to the development of human civilization [23]. Water inspires ideas about spatio-temporal change and transformation [24], with water bodies shaping human history and agricultural practices and enhancing modern economies [25]. People obtain a variety of non-material benefits from traditional water bodies, including cultural heritage and environmental education services [26].

Assessment and simulation of the relationship between water bodies and urban fabrics can deepen our knowledge of the interaction between hydrogeography and cultural landscapes. In addition to applying remote sensing techniques to monitor a time series of water quality [27], historical maps and aerial images were used to estimate the decreasing area of land use between 1880 and 2018 [13]. More detailed GIS data should be retrieved from historical map sources to clarify the trends in local development and establish a record of resilience through a quantitative estimation of changing land types and areas. Related 3D models should also be developed to create a more efficient interface of interaction by using augmented reality (AR) [28] to extend the efficacy of geospatial data.

Heritage and fabric should be considered an integrated issue and represented using auxiliary platforms of interaction and visualization. GIS, UAV, and AR have been collaboratively applied in facility management [29] and in the virtual reconstruction of historical buildings [30] and temples [31]. A combination of BIM, GIS, and AR has been applied to the operation and maintenance of gas utility pipelines [32]. Applications combining UAV and AR also show considerable usefulness in retrieving rock mass [33] or in processing building models for cultural tourism and 3D web-based applications [34]. Additionally, game engines have been applied to develop communication or interactive visualization platforms for heritage in wooden buildings [35], in ancient cities [36–38], at large-scale heritage sites [39], for lighting and materials [40], and for pedagogical tools [41].

Current geospatial data and the inspection of pond fabrics using GIS, UAV, AR, or game engines can be beneficial for the representation and interaction of urban fabrics. In an effort to investigate regional coordination or urban resilience, both the assessed and simulated results should be collaboratively applied to interactively illustrate fabric dynamics.

3. Materials and Methods

In order to assess the historical development of hydrogeography, data were retrieved from historical maps under a gradually developing sequence of scale or complexity in terms of urban fabric and traffic infrastructure. The assessment focused on the peripheral areas of eight farm ponds and traffic infrastructures in Taoyuan. Images from different sources were overlaid to differentiate the evolved boundaries. Maps and images were cross-inspected, traced, exported, and their areas estimated to verify the increasing or decreasing trends of ponds. UAV images of the eight ponds were used to construct 3D mesh and point models to visualize and interact with the characteristic fabrics of cross-pond peripheries (Figure 2).

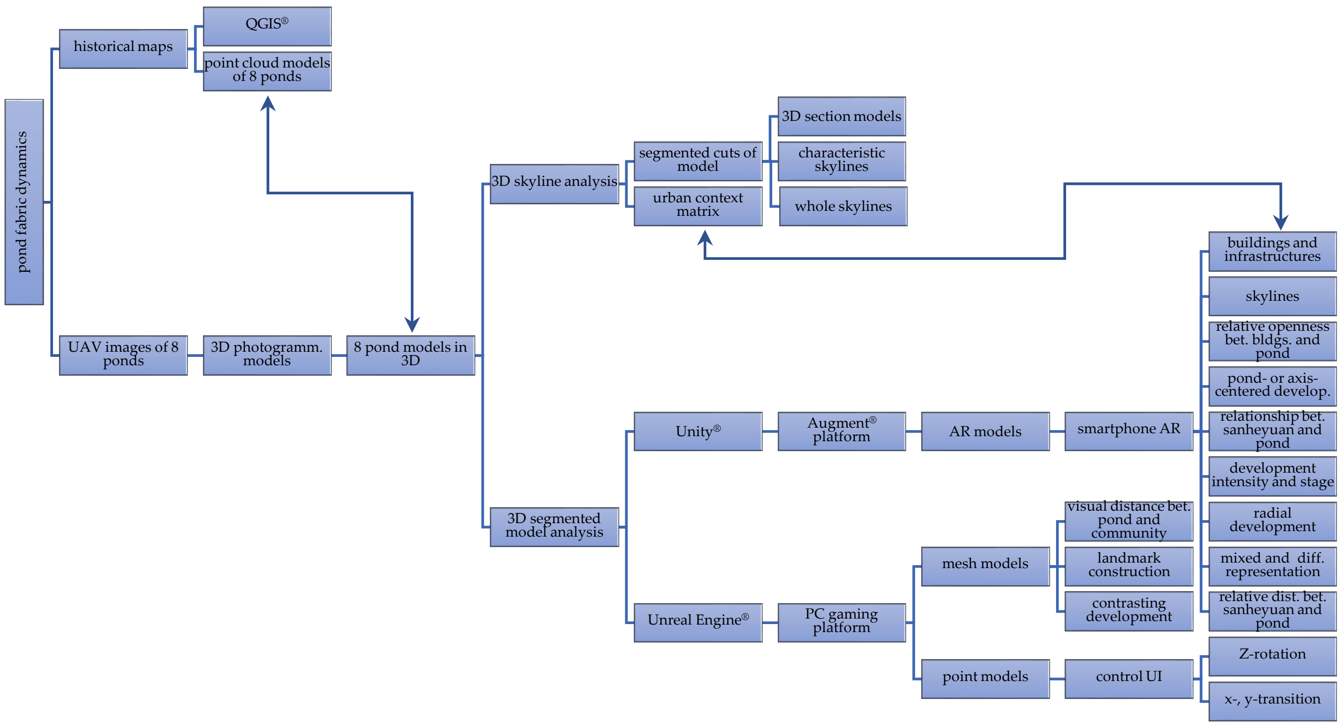


Figure 2. Research scope and implemented platforms for visualization and interaction.

Prior to inspecting and comparing as-built 3D remote sensing data, 3D models have to be prepared with sufficient detail for an interactive display environment. Considering the number of study areas in fields, a UAV was selected to obtain images, generate 3D photogrammetric models, and convert them to AR models afterward to be used by a smartphone app. In order to verify the quality of the models, sections were established to inspect the skylines. During the inspection of these models in general 3D programs, it should be feasible to develop a matrix for the urban elements of interest. The models and urban context should also be useful for subsequent simulations in AR and/or gaming engines. Although a smartphone screen is small, the device should be able to download several models and compare multiple skylines at the same time. Eventually, these models will be able to work on different platforms and interfaces, and it will even be possible to manipulate them in outdoor environments with cloud access available.

3.1. Map Resources and Cross-Referencing

The applied maps and images included information retrieved from the Research Center for Humanities and Social Sciences (RCHSS) [42] (associated with Taiwan Geospatial One Stop (TGOS) [43] and the National Land Surveying and Mapping Center (NLSC) [44]), Google Earth Pro®, and Google Maps®. The maps and point cloud models adopt the coordinate reference system (CRS) of Taiwan EPSG:3857, WGS 84/pseudo-Mercato and EPSG:32651, WGS 84/UTM zone 51N. "A 100-year historical map of Taiwan" [42] (Figure 3) was mainly applied to inspect local chronological evolvement. The scale of old maps varies, but the maps were rescaled in order to be overlaid with a new coordinate system. Topographic maps are linked to the GIS of "A 100-year historical map of Taiwan" at 1:25,000, or 1:50,000 for old maps.

Figure 3. The applied historical map: (**a**) "A 100-year historical map of Taiwan" and Taoyuan; (**b**) relative locations of ponds and infrastructure on an old Shimen Reservoir irrigation map [42].

3.2. Evolvement Assessment

Historical maps were cross-inspected to define evolvement from the earliest to the current fabrics using historical hand drawings, satellite images, aerial images, government survey results, and E-maps (Figure 4). The measurements included the areas of ponds and buildings (Figure 4).

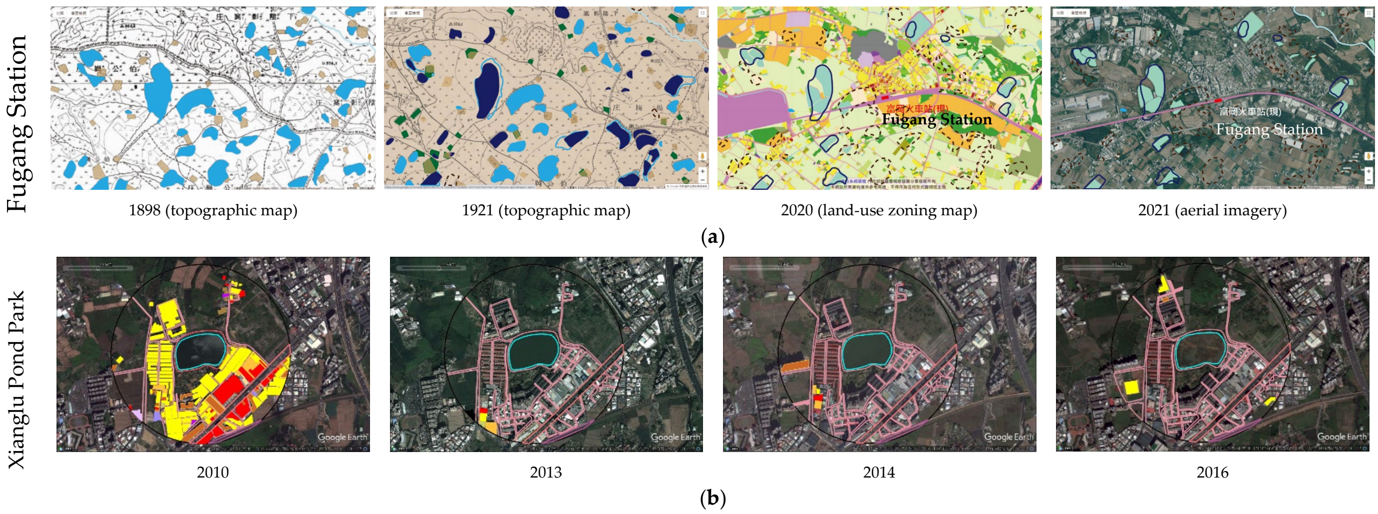
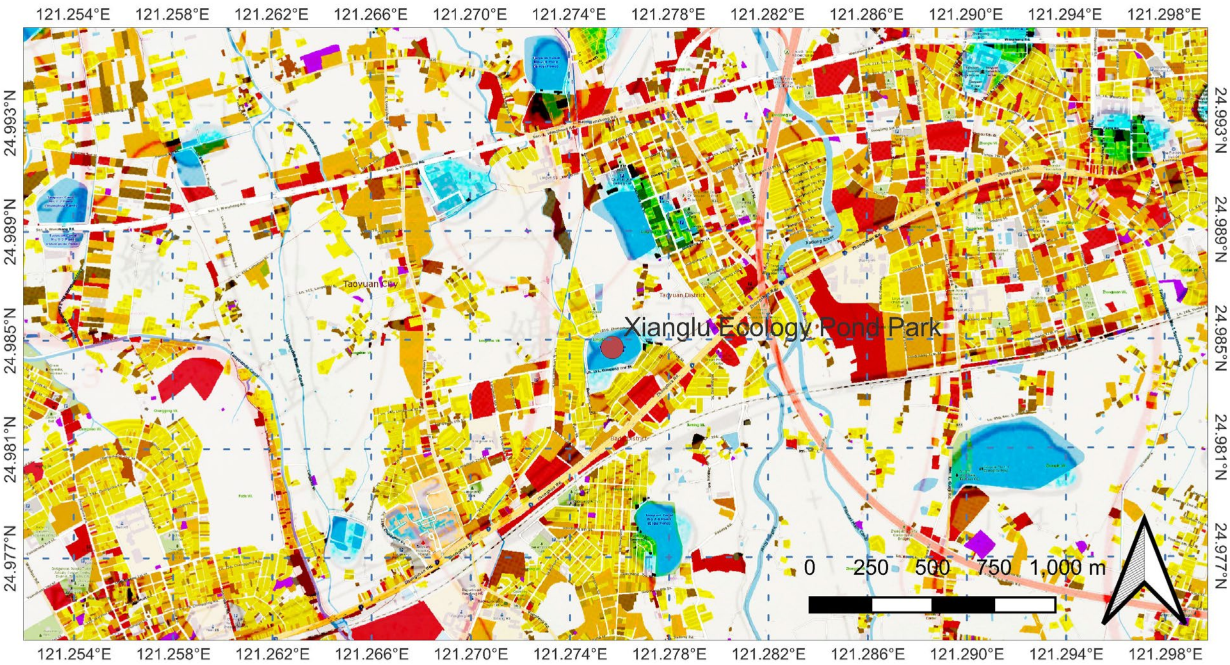


Figure 4. Assessment of subject incidence according to hydrogeography and building areas: (**a**) Fugang Train Station; (**b**) Xianglu Pond (yellow: residence; red: commercial use).

Paired maps were overlapped to highlight the differences between them using selected filters or options (i.e., multiple or invert in symbology, QGIS®(v. 3.22.5, free software)). Figure 5, for example, presents ponds modified through offset boundaries and those that disappeared under peripheral buildings between 1965 and 2023 based on a 3D point cloud model created from UAV imagery.

3.3. UAV-Based 3D Reconstruction

The assessments and paired comparisons were further verified using an as-built 3D reconstructed model (Figure 6) and compared to determine similar geographic characteristics using augmented reality (AR) (Figure 7). An unmanned aerial vehicle (UAV) (Dji® Phantom 4 Pro, Shenzhen, China) (Figure 6a) was used to obtain images along a planned path (Figure 6b). The 3D reconstruction was achieved through photogrammetric modeling using Zephyr® (V7.0, 3DF®, Verona, Italy) to create point cloud models and mesh models (Figure 6c). The mean reprojection error histograms and reports are available in Figure 6d–g.



(**a**) 1965 irrigation map vs. now

(**b**) 3D model and Taiwan E-map (EN) (**c**) 1965 irrigation map (**d**) Land survey type 5: architecture

Figure 5. Exemplification of evolved urban fabrics in terms of propagated buildings next to Xianglu Pond: (**a**) ponds were propagated in maps [42] by three demolished ponds and at least 10 newly developed small ponds with/without deformed shapes circled; (**b**) 3D model and Taiwan E-map (EN) [42]; (**c**) 1965 irrigation map [42]; (**d**) Land survey type 5: architecture [42] (yellow: residence; red: commercial use).

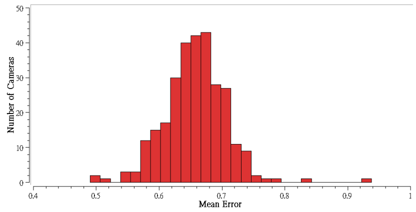
3.4. Interaction Comparison of Pond Peripheries Using AR and Gaming Platforms

The 3D models verified the urban context from the as-built point cloud model and historical maps in QGIS®. Three-dimensional reconstructed models were directly used to analyze the newly evolved fabrics using projected 3D skylines (Figure 7a). Ponds, either whole or in purposely segmented parts, helped identify and highlight dominant constructions. A context matrix was created as a summary of differences.

The segmented fabric parts were converted into AR models and uploaded to the Augment® (v. 5.6.1+30711, 2020–2024, Augment SAS, Paris, France) platform (Figure 7b) for interactive inspection using smartphone AR (Figure 7c,d). An overlapping or side-by-side inspection of fields or virtual fabrics was conducted. The AR models were cloud-assessed by scanning their QR codes. The AR simulation was mainly carried out on an iPhone® 12 Pro Max 6 GB Ram/256 GB (Apple®) smartphone, but we also used newer models like the iPhone® 14 Pro Max 6 GB Ram/256 GB and older models like the Xperia® 1 II (Japan, Sony®).

The gaming platform Unreal Engine® (UE®) (v. 5.3, Epic Games®, Cary, North Carolina) was used on a PC (Figure 7e,f) to handle mesh models or large point cloud models up to 1 GB. The models were directly converted from dense point clouds in Zephyr® into pts format (Figure 7g,h). The detailed description of the urban context, in addition to the Augment® platform, facilitated a more intuitive level of interaction.

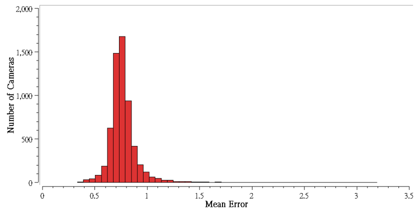
(**a**) (**b**) (**c**) (**d**)



(**e**)

Quick info.	Dji®	Xianglu Pond Park—2024	Xianglu Pond Park—2022	Public Pond—2022
		Phantom 4	Phantom 4	Phantom 4 Pro
	Project	Workspace-20240105-1	Shanlu-20220711	20220118
	Date	6 January 2024	11 July 2022	18 January 2022
	Program	3DF Zephyr	3DF Zephyr Education	3DF Zephyr Education
	Version	7.511	6.507	6.010
	Camera	289/290	289/290	6038/6317
Statistics	Camera Name	DJI FC330	DJI FC330	DJI FC6310S
	Resolution	4000 × 3000	4000 × 3000	5472 × 3648
	3D points per image	1220	1170	2415
	Oriented camera	289	289	6038
	BA Mean Square Err.	0.630956 px	0.673802 px	0.85945 px
	BA Ref. Variance	0.369026 px	0.402356 px	
	Mean GSD	0.0586289	0.0584446	0.0189691

(**g**)

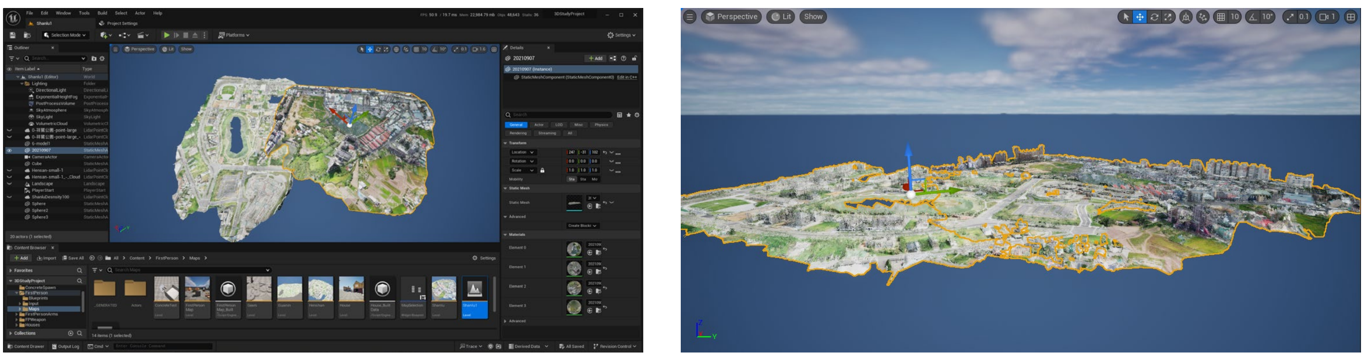


(**f**)

Figure 6. UAV-related information and photogrammetry report based on exemplification of Xianglu Pond: (**a**) Dji Phantom 4 Pro®; (**b**) UAV path; (**c**) UAV photogrammetry-reconstructed mesh model using Zephyr®; (**d**) mean reprojection error histogram: Xianglu Pond Park—2024; (**e**) mean reprojection error histogram: Xianglu Pond Park—2022; (**f**) mean reprojection error histogram: Public Pond—2022; (**g**) reports.

(**a**)

(**b**) (**c**) (**d**)



(**e**) (**f**)

Figure 7. *Cont.*


(g)


(h)

Figure 7. Screenshots showing examples of AR- and gaming engine-related modeling and manipulation: (**a**) overlapped layout to compare building height in Hengshan Calligraphy Pond with the trees in Bade; (**b**) AR model list; (**c**) screenshot of side-by-side comparison of two 3D AR models of ponds using an iPhone®; (**d**) situated application of smartphone AR in the laboratory; (**e**) Unreal Engine® editing interface for mesh models of Hengshan Pond (left) and Xianglu Pond (right); (**f**) mesh model-based skyline illustration; (**g**) PTS point model of Hengshan Pond presented in Unreal Engine®; (**h**) Xianglu Pond presented as a PTS point model.

4. Results

The assessed data illustrate the impact of traffic infrastructure on eight farm ponds and the gradual evolvement of urban fabric under different scales or complexities in pond peripheries. UAV images were used to create 3D models, sub-parts, and entities for comparisons (Table 1) and were inspected using PC gaming or smartphone AR platforms (Table 2). The numbers of 3D sub-models and 3D comparisons of Xianglu Ecology Pond Park, Hengshan Calligraphy Park, and Public Pond in Table 1 were obtained for the AR simulations only. The models of the other five ponds were also counted from the skyline analysis. There were more models obtained throughout the study process than the ones illustrated in the following figures. Sanheyuans, which are a type of old courtyard house with rooms on three sides, were an important and iconic house design in the agricultural era.

Table 1. Created or involved images, 3D models, sub-parts, and entities.

	Bade Pond Ecology	Chung Yuan Eco Pond Park	Blue Pond Park	Photovoltaic Pond (Shinwu)	Xiaoli Pond	Xianglu Ecology Pond Park	Hengshan Calligraphy Park	Public Pond	Subtotal
GIS aerial images	2	3	3	3	2	2	3	3	21
UAV images	347	359	418	382	738	290	1299	6318	10,151
3D pond models	1	1	1	1	1	1	1	1	8
3D sub-models	10	6	11	10	10	7	7	8	69
Skyline presentations	5	6	6	6	6				29
Sanheyuans	2			7	1			1	11

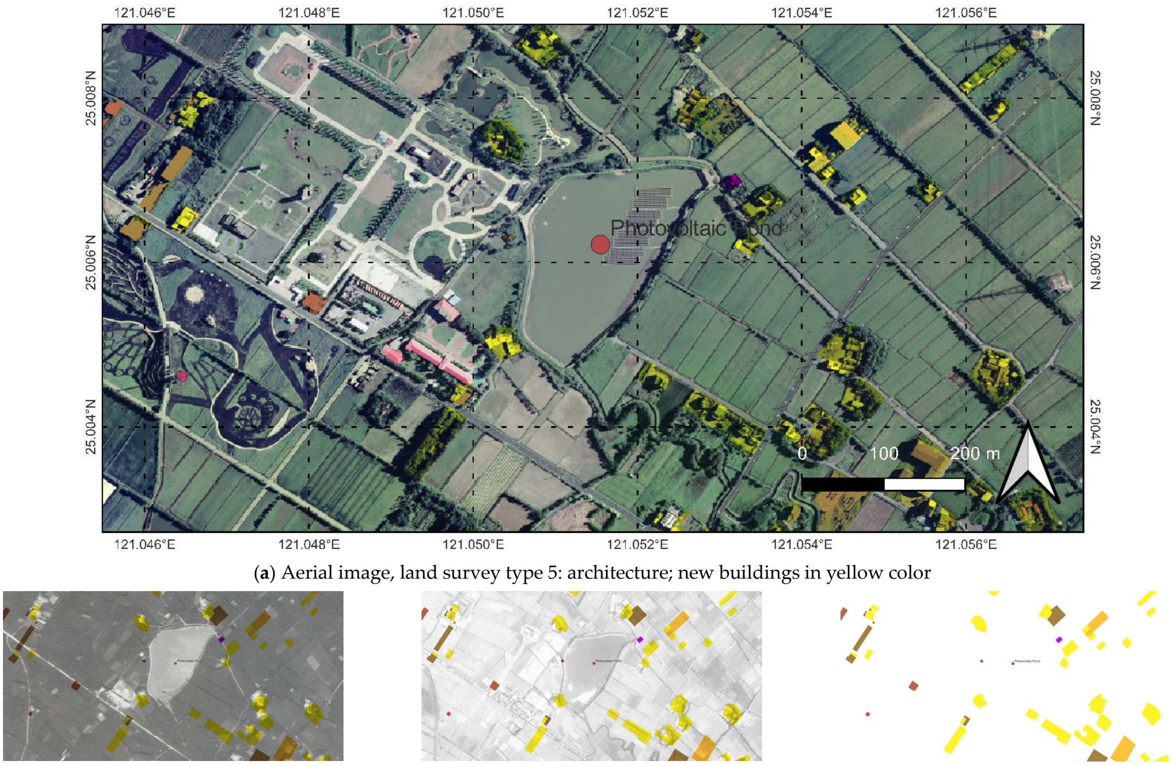
Multiple details were assessed in the 3D environment using augmented reality (AR) simulations to interactively assist in context visualization and inspection. The combination of the as-built fabric and historical maps enabled us to visualize the evolving scale using paired comparisons of old and new regions or the profiles of skylines under different emphases and orientations.

Table 2. AR and UE simulations.

	Buildings and Infrastructure	Skylines	Relative Openness Bet. Buildings and Pond	Pond- or Axis-Centered Development	Relationship Bet. Sanheyuan and Pond	Development Intensity and Stage	Radial Development	Mixed and Differentiated Representation	Relative Distance Bet. Sanheyuan and Pond	Subtotal
AR comparisons	6	4	5	6	6	2	3	17	6	55
AR models	13	8	3	12	4	10	6	29	15	100
UE® comparisons				2						2
UE® models				4						4

4.1. Fabric Dynamics between Historical Maps

Eight ponds were selected based on their history, designated role, and the major development type of buildings in their peripheries. The selections included two ponds located near the Green Line of the Taoyuan Rapid Transit System and six far away from it in order to explore their potential relationship with the concept of TOD. Each pond is surrounded by a specific urban fabric and has a distinguishable pattern of development. Figure 8 exemplifies the inspection process of an increased building area around Photovoltaic Pond in the non-urban planning area of Taoyuan. Historical aerial images from different years were overlaid to highlight the added buildings in yellow, with reference to government-initialized surveys. "Building" and "land" were assessed to reveal a trend across eight ponds from 2010 to 2020 (Figure 9a). The intersection occurred in the urban planning area.



(**a**) Aerial image, land survey type 5: architecture; new buildings in yellow color

(**b**) Satellite image 1965

(**c**) Satellite image 1974

(**d**) Land survey type 5: architecture

Figure 8. Example of an assessment of building area increments around Photovoltaic Pond in the non-urban planning area of Taoyuan: (**a**) aerial image with buildings added post-1965 highlighted in yellow; (**b**) aerial image: 1965 [42]; (**c**) aerial image: 1974 [42]; (**d**) government-initialized survey of buildings [42].

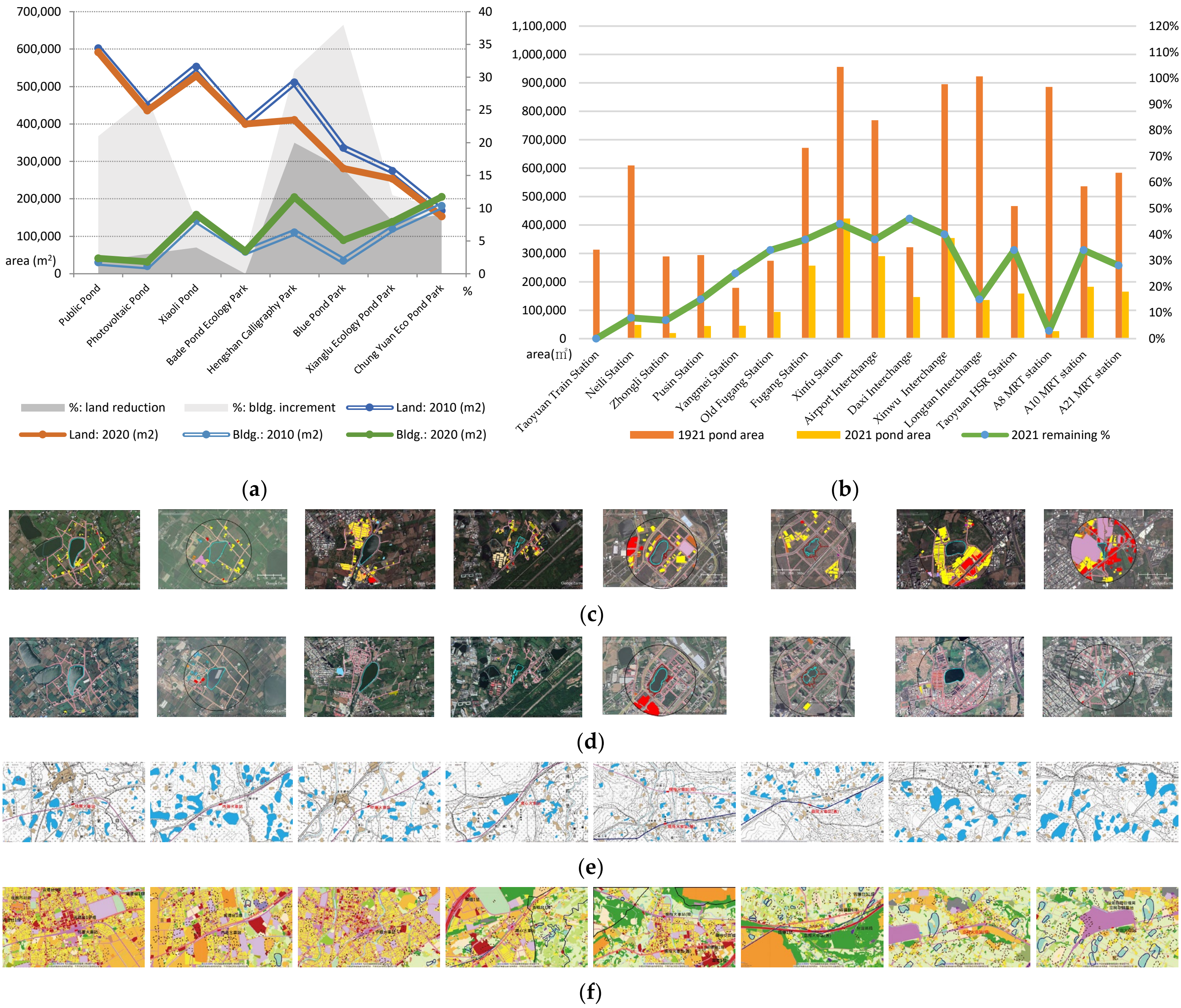


Figure 9. Assessment of the land area around the eight ponds and TOD-based infrastructures: (**a**) fluctuations in land reduction and building area increments around eight ponds from non-urban to urban planning areas; (**b**) farm ponds with land fluctuations near TOD-based infrastructure; (**c**) pond periphery: buildings in 2009 or 2010; (**d**) pond periphery: buildings in 2018 or 2019; (**e**) ponds around the train station periphery: 1898 topographic maps; (**f**) ponds around the train station periphery: 2020 land-use map. (yellow: residences; red commercial; blue: ponds; orange: mix use).

In order to highlight the impact of TOD, the areas of ponds were assessed near (a) local train stations; (b) provincial highways, national expressways, and system interchanges for airports; and (c) the Taiwan High-Speed Rail (THSR) and Mass Rapid Transit (MRT) stations (Figure 9b). The fluctuations in land use near TOD-based infrastructures were caused by the elimination of ponds to make way for transportation infrastructure (as degenerated landscapes) and the reactivation of ponds by infrastructure (as regenerated landscapes). Although TOD attracts populations and reactivates hydrogeography-related cultural landscapes, the new constructions inevitably made use of pond lands during the replotting process.

The maintained and reapplied pond spaces presented a tradeoff between the preservation of cultural heritage and the planning of traffic infrastructure in urban and non-urban planning areas as a result of TOD. Ponds in urban areas that benefit from TOD are located on the right and have higher building ratios (31% around Hengshan Calligraphy Park and 38% around Blue Pond Park) and lower land ratios. Although the area may vary depending on regional development, the highest in the non-urban planning area resulted from the promotion of an agricultural fair, with up to an additional 27% of building area. The 46% reduction in pond area around Daxi Interchange was another indicator of degeneration in the opposite direction to TOD-based instrumentation.

4.2. Three-Dimensional Models of Ponds

Eight ponds were used for the original 3D models (Figure 10) for the visualization and segmentation of fabrics and hydrogeography in the following sections.

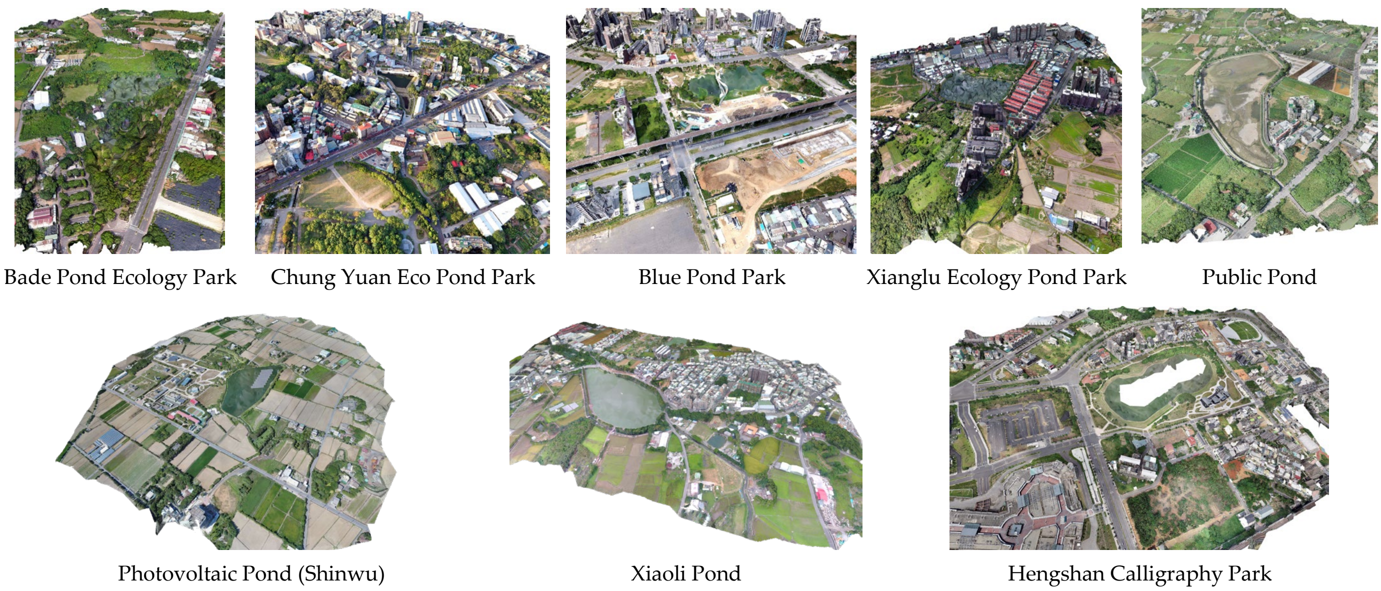


Figure 10. Three-dimensional UAV-assisted photogrammetric modeling of eight ponds and their peripheral areas.

4.3. Three-Dimensional Skyline Analysis and the Context Matrix of Ponds

Three-dimensional skylines were used to analyze newly evolved fabrics (Figure 11). The levels of development were categorized into residence, agriculture, industrialization, and public construction in terms of old and new houses, farmland and greenhouses, factories and waste management plants, or retail stores and traffic infrastructure. The items were visually identified and summarized into a matrix table (Table 3) to be used in the following simulations. In total, 29 skylines were found to demonstrate regional development through associated fabric segmentation.

Table 3. Pond context matrix.

	Total	B 1	B 2	B 3	B 4	C 1	C 2	C 3	C 4	C 5	BP 1	BP 2	BP 3	BP 4	BP 5	S 1	S 2	S 3	S 4	S 5	X 1	X 2	X 3	X 4	X 5
Sanheyuan	12	X	X	X	X											X	X	X	X	X	X			X	X
Community	13	X	X	X	X		X	X	X			X	X	X								X	X		X
Apartment	22	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X
Office	10					X	X				X	X	X	X	X							X		X	X
Retail	1												X												
Factory	15	X	X	X	X	X	X	X	X	X	X										X	X	X	X	X
Farmland	14	X	X	X	X											X	X	X	X	X	X	X	X	X	X
Greenhouse	9	X	X	X	X											X		X	X				X	X	
Recycling	6	X	X	X	X																		X	X	
Traffic infra.	5										X	X	X	X	X										
skyline included				veteran home		univ.	univ.	univ. park	univ. park	univ. park	const. park	const. park	const.	const. park	parkg. baseb. Park	school weather fair	school weather fair	school weather fair	const.	school weather fair	grave.	pond	pond		grave.

Note: B: Bade; C: Chung Yuan; BP: Blue Pond; S: Shinwu; X: Xiaoli; univ.: university; baseb.: baseball field; weather: weather station.

4.4. AR Interactive Analysis

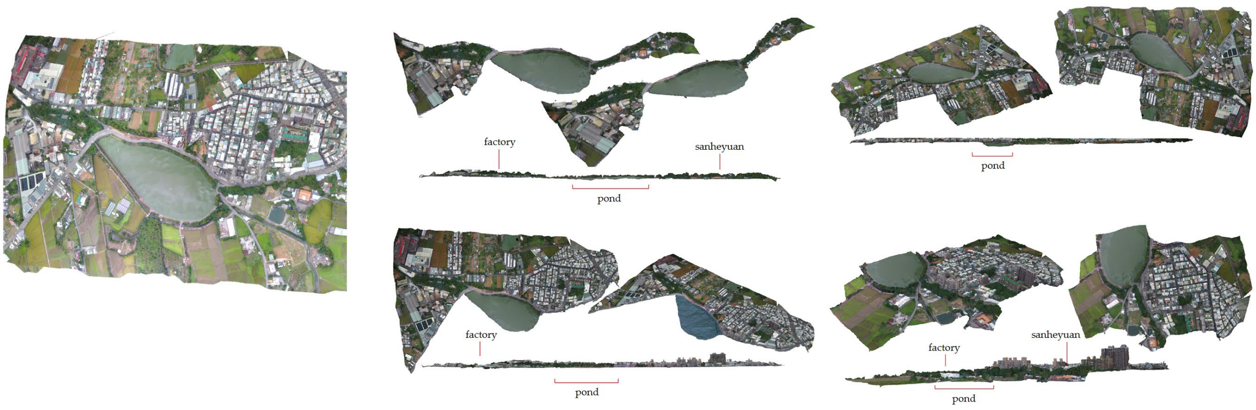
A 3D virtual dynamics analysis between fabrics and hydrogeography was conducted in AR as another step to assess the feasibility of the 3D models and context matrix. This interactive comparison presents a flexible visualization structure in AR models segmented from UAV modeling. Side-by-side or overlapping UAV models were configured to highlight regional characteristics, such as building types or sanheyuan–pond relationships. These models were cloud-accessible and compared using a smartphone. In total, 55 comparisons or inspections were made based on indicators related to pond development.

AR interactive analysis was conducted across nine categories (Figure 12).

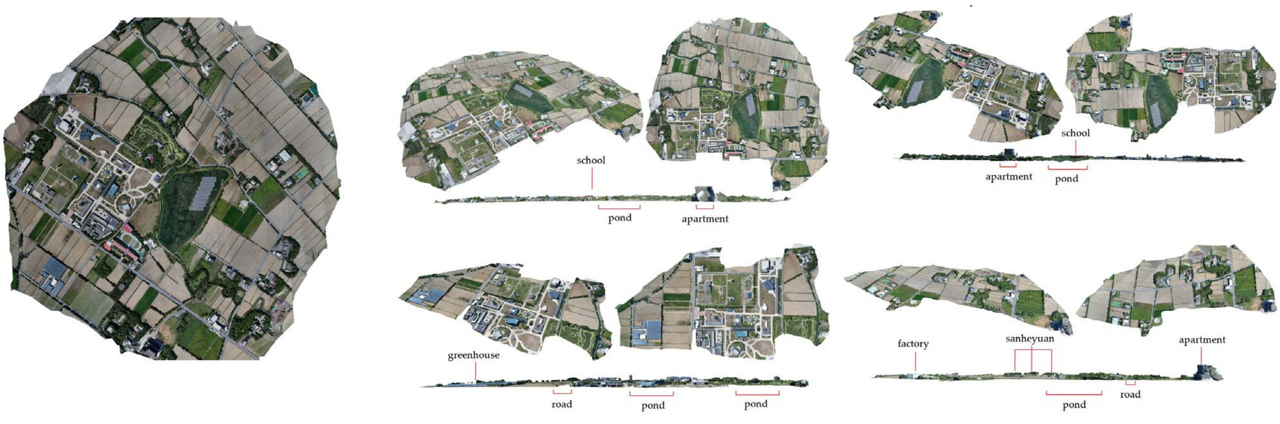
1. Buildings and infrastructure (Figure 12a): Buildings and infrastructure are indicators of development based on mass, height, or density. Examples include apartments, MRT stations, department stores, sanheyuans, and schools. The different 3D configurations of fabrics, which present the changes made over decades, especially stand out when multiple models are interactively allocated using different levels of adjacency and orientation.
2. Skylines (Figure 12b): The skyline is an indicator of the characteristic development of a local area compared with the open space of a pond.
3. Relative openness between buildings and ponds (Figure 12c): The relative openness is one of the factors that determine whether a pond periphery is over-developed. Interstitial space is usually missing or is merely presented by a pavement or a road.
4. Pond- or axis-centered development (Figure 12d): Various patterns have been developed to determine the peripheral areas of ponds to assess their geospatial characteristics, as indicated by red dash lines. The purpose of our side-by-side AR reference was two-fold: pond-centered comparisons and axis-centered comparisons. The former highlighted the volumetric differences in urban fabrics around ponds. The latter highlighted the pattern of occupancy along streets or the edge of the 3D model.
5. Relationship between sanheyuans and ponds (Figure 12e): A pond is a small-scale water reservoir that supports irrigation, people's livelihoods, and fish farming. Pond-centered AR models provide updated as-built information to reconstruct the spatial relationships between the original design and the new urban fabric after years of occupancy, as indicated by red dash lines. A few sanheyuans have kept the traditional layout of a moon-shaped pond in front of the house.
6. Development intensity and stage (Figure 12f): Each pond has a unique development type. In AR, ponds were aligned using stripes to illustrate how the urban fabric was formed in the peripheries.
    - Development intensity: Linear cuts of the eight ponds were made from one end to the next. Chung Yuan Eco Pond Park, which is located third from the front, has a higher residence density than other ponds, such as Public Pond. The intensity of development is made more visible when the AR view is tilted 45 degrees to reveal the skylines.
    - Development stages: Chung Yuan Eco Pond Park is surrounded by low-altitude buildings and factories. It was developed earlier than Blue Pond Park, which is located near a new district promoted by THSR station. Although the latter is still under development, the new region has taller residences and an MRT station located to the southeast. The combination of the elevated MRT and pond landscape presents a different scene to that of the street located next to old residences and factories.
7. Radial development (Figure 12g): The UAV models were segmented by stripped radial cuts starting from the pond center in order to highlight the specific characteristics of each pond. This process narrows down the dominant construction by illustrating relative variations in skylines across regions.
8. Mixed and differentiated representation (Figure 12h): The representation was made using building type with side-by-side layout and overlapped layout. Characteristic

building types include residences that feature a large number of diversified forms, from old sanheyuans to new communities, old elementary schools constructed in the 1960s, and new THSR-initialized urban planning in the 21st century. The unique sanheyuans were segmented into individual AR models for comparison.

9. Relative distance between sanheyuans and ponds (Figure 12i): The relative distance illustrates the initial relationship between residences and water sources. The infill between sanheyuans and ponds demonstrates a transition from farmland to new constructions. The semi-enclosed courtyards of sanheyuans were used to process farm goods. The AR models were placed in a parallel layout, with the farmland located between them, to highlight the remaining old sanheyuans and ponds. A physical ruler was placed in the background as a reference for the scaled AR model. As a result, we determined that most of the infill is occupied by residences and interrupts the old axis of the cultural landscape.



(**a**)



(**b**)

Figure 11. *Cont.*

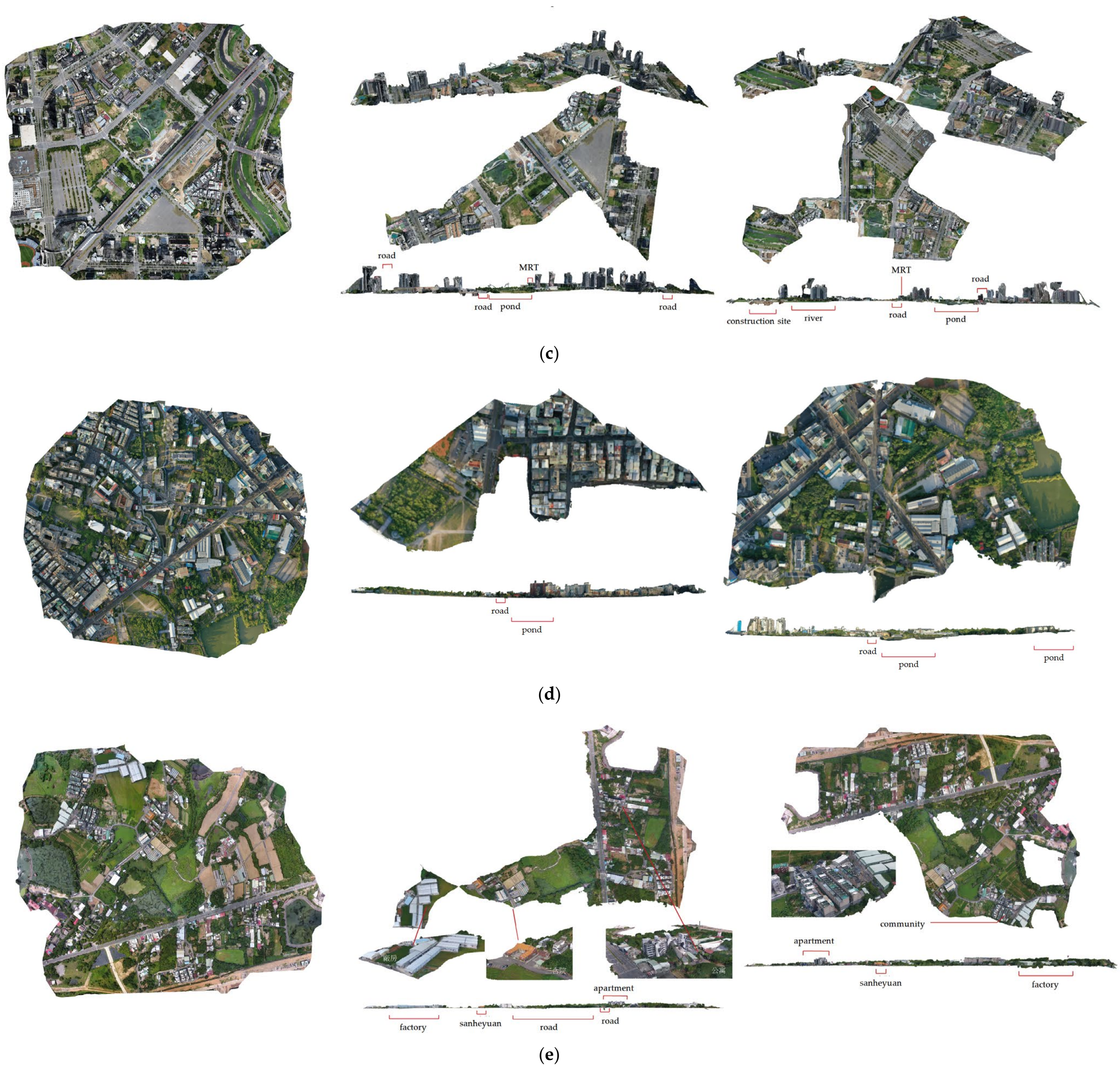


Figure 11. The variations of old and newly evolved skylines: (**a**) Xiaoli Pond; (**b**) Photovoltaic Pond (Shinwu); (**c**) Blue Pond Park; (**d**) Chung Yuan Eco Pond Park; (**e**) Bade Pond Ecology Park.

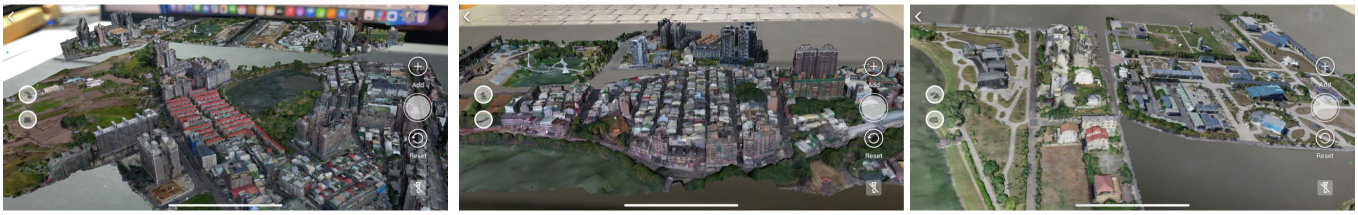
(**a**) Buildings and infrastructure.

Factory (left) vs. outlet (middle) vs. MRT station (right)

Blue Pond (left) vs. Shinwu (right): MRT station and depart. store vs. sanheyuan and apartments

elementary school and sanheyuan (front) vs. department store (back)

(**b**) Skylines.

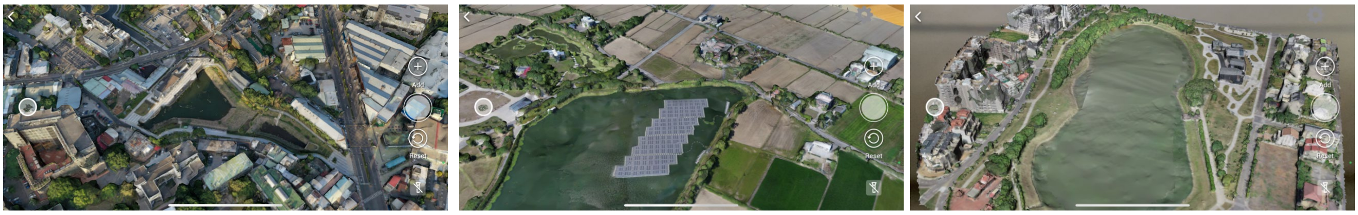


Xianglu (front) vs. Blue Pond (back): railroad activated development

Xiaoli (front) vs. Blue Pond (back): uniform vs. non-uniform development in skylines

Hengshan (left) vs. Shinwu (right): apartments and museum vs. agricultural fair facilities

(**c**) Relative openness between buildings and pond.



Chung Yuan: enclosed by sidewalk, campus, and old residences

Shinwu: enclosed by farmlands

Hengshan: enclosed by museum, internal/external circulation system, and townhouses

(**d**) Pond- or axis-centered development.

Public Pond (left) vs. Xiaoli (right): linear development along street

Xianglu (left) vs. Hengshan (right): high-density residence vs. low-density museum periphery

Chung Yuan (left) vs. Xianglu (right): circulated development around pond

(**e**) Relationship between sanheyuans and ponds.

Shinwu: facing pond with clear view

Public Pond: separated by other residences

Xiaoli: partially separated by other constructions

(**f**) Development intensity and stage.

Figure 12. *Cont*.

Shinwu (left) vs. Chung Yuan (right): agricultural fair-reactivated develop. vs. campus peripheries

Different development intensities across ponds

Different development stages bet. Chung Yuan Eco Pond Park (front) and Blue Pond Park (back)

(**g**) Radial development represented by radial cuts.

Top view

Perspective view 1

Perspective view 2

(**h**) Mixed and differentiated representation.

Public Pond (left) vs. Xiaoli (right): sanheyuan surrounded by trees vs. with additional pond in front and hillside in the back

Hengshan (left) vs. Bade (right): elevated residences vs. leveled landscape

Shinwu (left) vs. Chung Yuan (right): enhanced difference in clustering between agricultural fair and university campus

(**i**) Relative distance between sanheyuan and pond (not in scale).

Shinwu

Public Pond

Xiaoli

Figure 12. Screenshots of AR interactive analysis in nine categories.

4.5. Unreal Engine Interactive Analysis

A 3D virtual dynamics analysis between fabrics and hydrogeography was conducted using a gaming engine to assess the feasibility of the 3D models and context matrix. The PC gaming engine UE® was applied to interactively allocate pond models as an extension to the corresponding comparisons conducted in the Augment® platform. What made this platform different was the efficient and intuitive interaction based on adjustments made to (1) the visual distance between the pond edge and the regional center of the community; (2) the dominant construction, such as the tallest or most representative building in the region; and (3) the local development center. The results provided support for the inspection of differentiated development between urban and non-urban areas, for example, Xianglu Pond and Hengshan Pond (Figure 13).

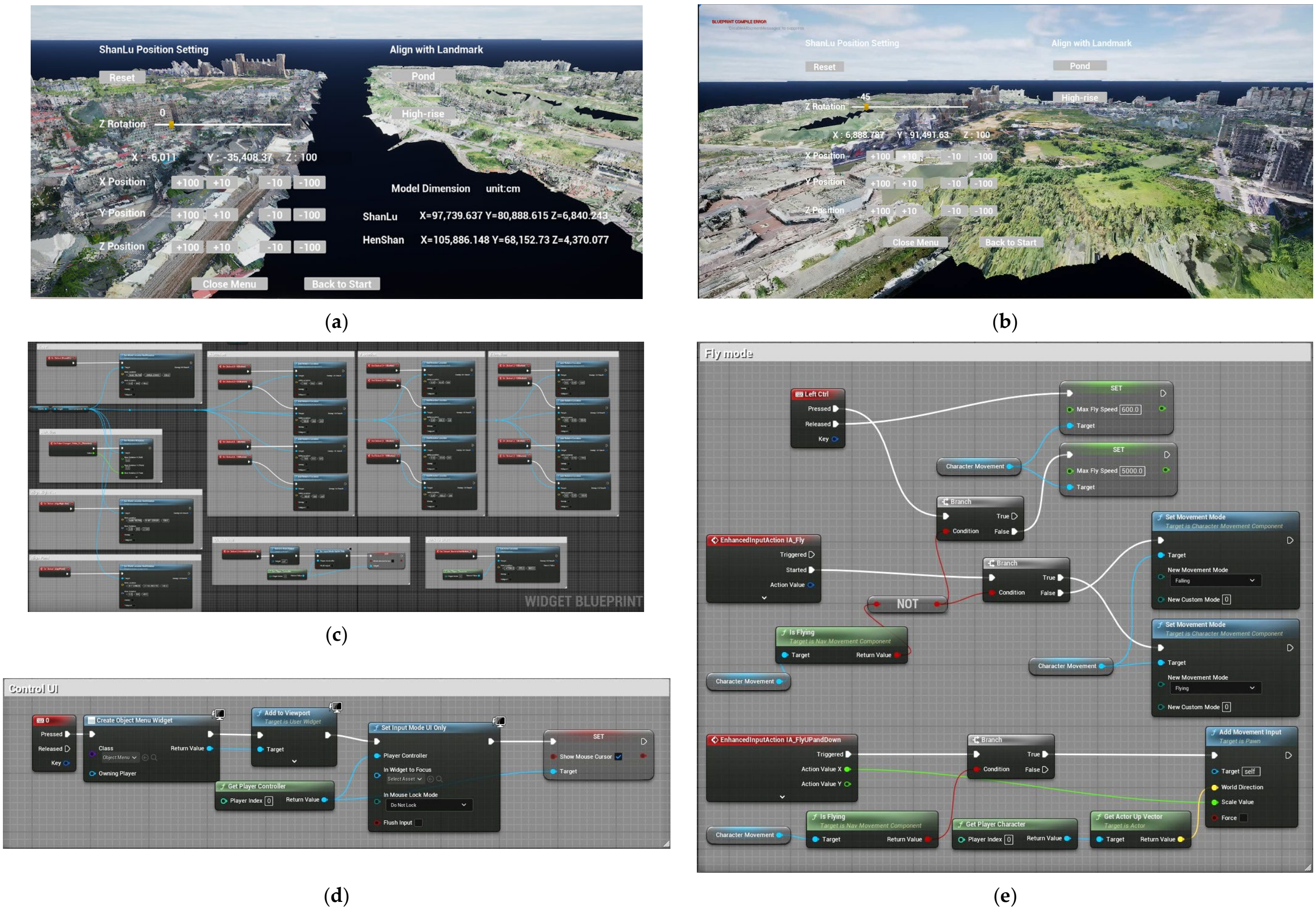


Figure 13. Unreal Engine® editing interface for mesh models of Xianglu Pond (left) and Hengshan Pond (right): (**a**) Z-rotation control; (**b**) transition control (in cm); (**c**) blueprint of interface; (**d**) control UI; (**e**) fly mode.

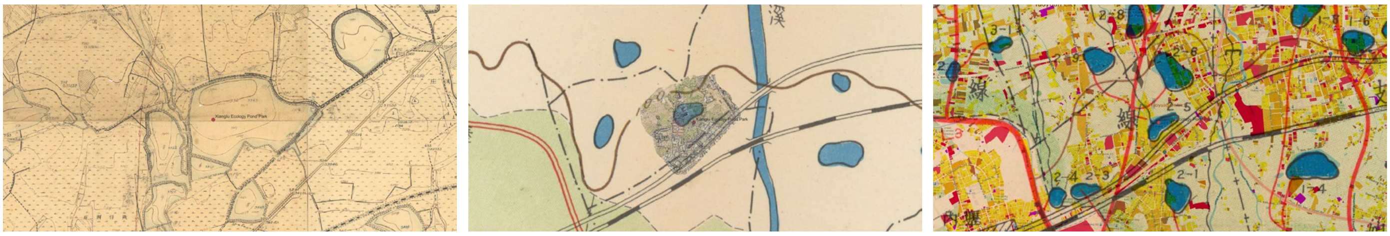
The file size of a 3D model was as large as 1 GB or over 10 million points. The formal AR simulation was restricted by model size and the number of loaded models, which was alleviated using UE®. This gaming engine was also an alternative to the other AR platform, with a limitation on the size of the cloud model.

5. Discussion

While the 3D models enabled comparisons to be made between historical maps, they were also extensively applied in 3D skyline analysis and 3D virtual simulations using AR and the gaming engine. The urban context matrix across ponds was observed in AR and, consequently, enabled another level of inspection, from buildings and infrastructure to the relative distance between sanheyuans and ponds. We found that the hydrogeography and cultural landscapes evolved in terms of their interstitial space, role substitution, and conflict resolution. Evolving interstitial space has shown potential regarding its passive and active approaches to the alternation of spatial structures.

5.1. Evolving Interstitial Space

Interstitial space, which is the buffer between an old water body and urban space (Figure 14), plays an important role in merging an old setting with new fabrics. This space provides potential for diversified evolvement. It is likely that a pond will be isolated in the middle of the area, enhancing connections to the community and reactivating connections to the past through its cultural context. The distance between the nearest buildings and ponds illustrates different ranges of interstitial space around Xianglu Ecology Park. Newly excavated or vanished ponds constantly rearrange the fabric order. The Wetland Act [45] provides limited protection, since other aspects of predefined land use may be changed at any point.



Assembled topographic maps of irrigation regions in Taoyuan (year unknown)
(**a**)

1965 irrigation zoning map (Taoyuan Irrigation Association)
(**b**)

1965 irrigation zoning map vs. land survey type 5: current architecture
(**c**)

Figure 14. Evolving hydrogeography and interstitial space: (**a**) original pond topographic maps [42]; (**b**) altered irrigation zoning map [42]; (**c**) another altered version derived from 1965 irrigation zoning maps (Shimen Irrigation Association) [42] and land survey map [42] (yellow: residence; red: commercial use; green: agriculture, preserved area).

The alternation of history constitutes a typical stage in the evolvement of the cultural landscape, which must be redeveloped to maintain its structure and keep it from being destroyed. An example of this is the axis that connects sanheyuans and ponds, from an open pond to one that is disturbed by new construction. While old infrastructure may be updated to a more well-developed system, the diminished role of ponds has reduced irrigation demand and, consequently, led to the removal of old infrastructure systems, as they are not part of the renewal process. This explains why ponds are reactivated as ecological parks to promote the cultural landscape and regional tourism in a sustainable manner.

5.2. Role Substitution of the Agricultural Fabric

Subject-dominated planning presents a general description of (de)valuated results owing to the shared adaptation of new measures in a redefined order between hydrogeography and architecture. New manners of preserving water bodies have emerged for reasons that range from resolving degeneration to recreating (or enforcing) demand for community retaining ponds, sites for photovoltaic energy, or demonstrative education sites for new irrigation systems. Originally, ponds controlled how the urban fabric developed in terms of layout or infrastructure. As ponds remained unchanged over decades, the urban factors that had evolved contributed to redefining them. It was found that the order of their spatial structure was broken and subjected to the order of the peripheral urban fabric, which was initially defined by ponds. The replacement of their fabric led to land use that had either a positive impact on the community, like a reactivated park, or a negative impact, like a recycling plant.

5.3. Conflict Resolution of Policy and TOD Instrumentation

Policy contributes to the evolvement of and differentiation between old and new fabrics. The Wetlands Act, which is applied to ponds in (non)urban areas, restricts the unauthorized construction of ponds. In this study, the conflicts were presented on different scales and under various paces of acceleration. We found that the early accomplishments of facilities in meeting function-dependent demand were eventually replaced by land shortages, even when policies were applied.

Examining the vicissitudes of hydrogeography and cultural landscapes resulted in a more productive discussion of urban replotting using new circulation systems around ponds. The major infrastructure projects involved overall urban transport development, such as the Taiwan Railroad, THSR, MRT airport, and the MRT green line in Taoyuan. The transportation of farm goods was replaced by more efficient networks built to serve people, while railroads were replaced by MRT or THSR. It seemed that the advantages of the new TOD strategy were preferred over the diminished role of the old hydrogeography.

The role of water bodies was redefined by irrigation and TOD. The new TOD strategy created a different type of land use in pond peripheries. The once-important resources and social order provided by water bodies degenerated. The promotion of TOD and the fair around water bodies in Taoyuan was replaced by urban reform and renewal, which represents a more straightforward form of instrumentation.

The hydrogeography did reactivate the cultural landscape with the assistance of TOD. TOD was newly deployed near some ponds to create new opportunities to attract visitors. We found that the TOD available around ponds has changed along the airport MRT and green line MRT in Taoyuan. There are 61 ponds intended for use in parks. As part of the green and beautification engineering project, related benefits include the promotion of local tourism and improvement of the quality of life via hydrophilic facilities and leisure facilities. Combining geographic characteristics and cultural activities, such as lantern festivals, is an active strategy that binds new facilities, renewed fabrics, and new programs into new urban parks. As a result, a new, more sustainable pattern is created.

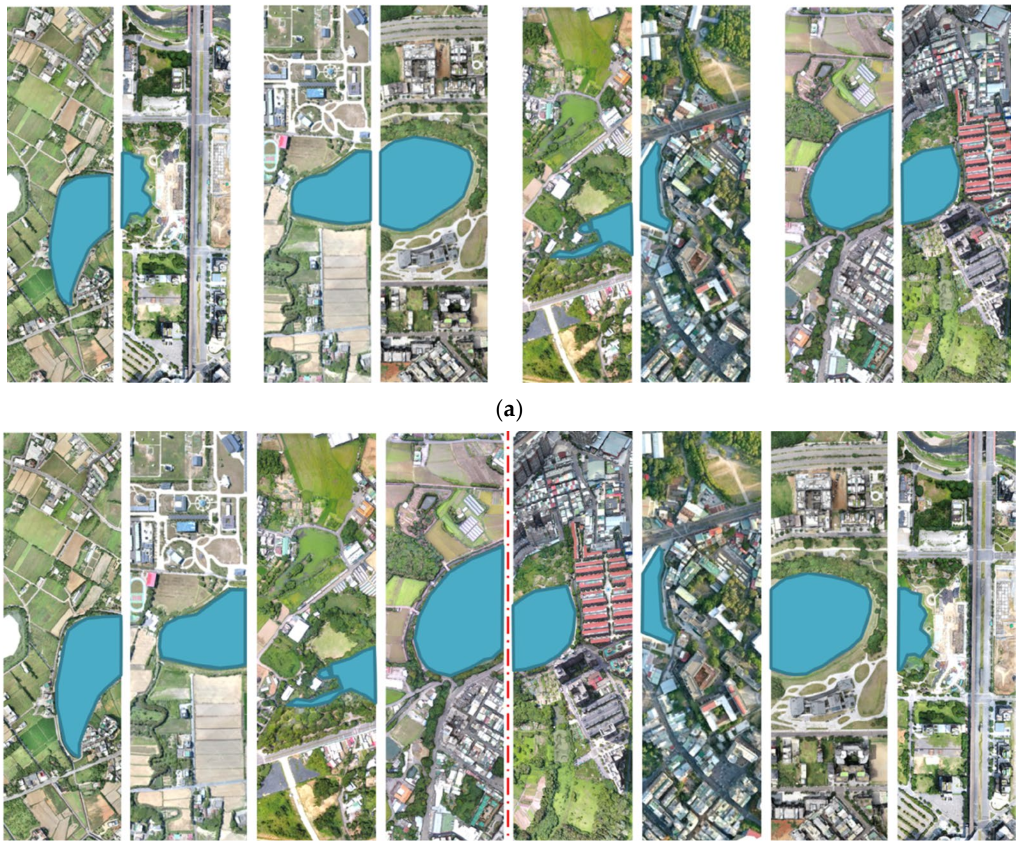
5.4. Three-Dimensional Virtual Dynamics

The 3D visualization of interstitial space, in addition to remote sensing images, clarifies patterns of obsolescence and reactivation. Segments were produced with different emphases to illustrate the local identity of major buildings and landscapes. The point models derived from UAV imagery modeling facilitated the simulation, in which old parts of the model could be removed to highlight the difference caused by evolvement. This is also applied to the fabric around the pond areas between old houses and new apartments. We found that the changes were significant, while the detail enabled an adjustable viewpoint and more realistic scaling with reference to the human body than remote sensing satellite imagery.

We interacted with three-dimensional data in AR using a smartphone or gaming engine. Special layouts were arranged in pairs or groups between urban (left) and non-urban (right) planning areas (Figure 15). The AR interaction enabled a more realistic comparison of the land use of different ponds than the 3D view in QGIS®. This interaction added an important sense of spatial structure in striped form. We found that the gaming engine can handle large point models with higher detail. With limited programming processes, paired comparisons can be published in more intuitive modules.

5.5. Relationship between Assessment and 3D Simulation

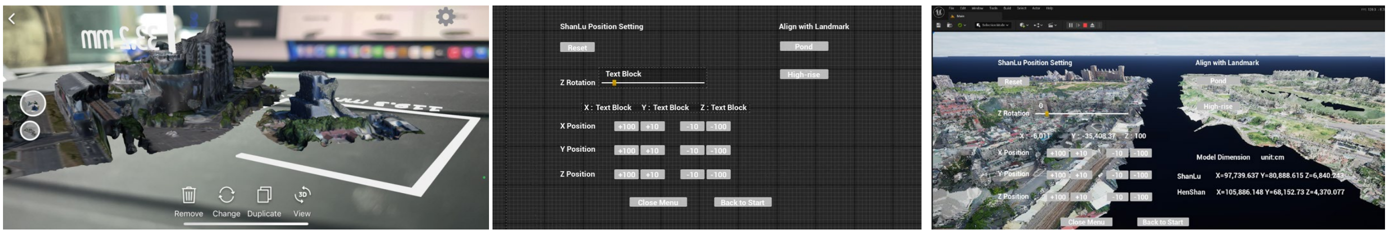
Numeric assessment and 3D as-built representation can be mutually beneficial. The regional assessment can be better explained if (1) the whole region can be divided into sub-parts in the study, and (2) the dimensions can be displayed to achieve a combinational representation of the physical form of the sub-parts and their sizes. This concept was achieved using two approaches: (1) we displayed the dimensions of width and length using a boundary box in Augment® AR simulation (Figure 16a), and (2) we used numeric inputs of displacement distance and rotation angle to enable detailed adjustment of the entire model by referring to target objects, like open space or main buildings, in the paired comparison (Figure 16b,c). The original 3D models were created on a 1:1 scale. With the dimensions displayed or the control of the numeric input, the sense of scale and dimension are available in simulations conducted in AR and gaming engines. The user can enter the specific distance in meters or degrees to move or rotate the model. Although the UE® interface was specifically customized for the paired comparison in this study, we are certain that the same interface can be applied to more models.



(**a**)

(**b**)

Figure 15. Ponds highlighted in blue and peripheral areas illustrated by projected UAV-based photogrammetry models: (**a**) paired comparisons between urban (left) and non-urban (right) planning areas; (**b**) fabric variation between non-urban (left) and urban (right) planning areas, separated by a red center-line.



(**a**) (**b**) (**c**)

Figure 16. Dimensions displayed in simulations: (**a**) dimensions in Augment® AR; (**b**) design of numeric inputs of displacement distance and rotation angle; (**c**) exemplification in UE®.

The traditional assessment in "Section 4.1. Fabric Dynamics Between Historical Maps" can be assessed interactively by looking at the fabrics in more detail in the two simulations conducted in AR and UE®. After preparation of the 3D models described in "Section 4.2. Three-dimensional Models of Ponds", the target urban fabric can be modeled for use in traditional architectural and urban studies like skylines, as in "Section 4.3. Three-dimensional Skyline Analysis and the Context Matrix of Ponds", and even to create a pond context matrix, as in Table 3. Moreover, the matrix contents can be assessed or visualized via two methods of simulation, as in "Section 4.4. AR Interactive Analysis" and "Section 4.5. UE® Interactive Analysis."

This does not mean the traditional assessment presented in "Section 4.1. Fabric Dynamics Between Historical Maps" can be completely replaced by these two simulations.

However, this concept was executed from Section 4.1 to Section 4.5 with regard to pond fabrics. This study found that each simulation method has its own advantages and is appropriate for gaining knowledge in different areas.

This study aimed to assess the interaction between urban fabrics and eight farm ponds in Taoyuan. Our simulations and pond context matrix facilitated discussions of the following: "Section 5.1. Evolving Interstitial Space", "Section 5.2. Role Substitution of the Agricultural Fabric", and "Section 5.3. Conflict Resolution of Policy and TOD Instrumentation". The earlier results obtained using historical maps and follow-up simulations have fulfilled the purpose of this study.

6. Conclusions

One of the most effective approaches to exploring the historical context of a city is to examine its buildings next to farm ponds. Hydrogeography and cultural landscapes present a cross-alliance and share a certain level of similarity in terms of the obsolescence of a pond's original functionality, followed by its reactivation or reform. Farm ponds, as a cultural landscape, represent the sustainable utilization of water resources and a system that has been resilient to topological changes over time. We found that the TOD available around ponds has changed along the airport MRT and green line MRT in Taoyuan.

Numeric assessments and 3D as-built representations are mutually beneficial. The UAV-assisted 3D models led to the skyline analysis and the finding of a context matrix observed in a smartphone AR and gaming engine simulation. The area assessments of 8 ponds and 16 TOD-based infrastructures were followed by 100 AR cloud-derived models in nearly 55 paired AR comparisons in 9 categories. As a result, ponds contribute to the peripheral fabric via different patterns of evolvement. The UAV-assisted 3D models, which enabled comparisons to be made between the historical maps and the skyline analysis, allowed the context matrix to be observed in smartphone AR, from buildings and infrastructure to the relative distance between sanheyuans and ponds. A gaming engine was also an alternative solution to verify the context matrix with fewer limitations on the size of the cloud model.

We found that the obtained demolition ratio of ponds highlights a novel approach that employs tools and converted data formats across ponds to enrich our comprehension of this topic in an interactive and intuitive manner. Three-dimensional virtual dynamics and a combination of heterogeneous platforms also provided practical instrumentation for preserving heritage.

Future research should explore the use of more diversified measures and gaming modules to interpret the relationship between hydrogeography and intangible cultural landscapes.

Author Contributions: Conceptualization, methodology, software, validation, formal analysis, investigation, writing—original draft preparation, visualization, and data curation: N.-J.S., Y.-T.T., Y.-T.Q., and T.-W.H.; UAV modeling of right ponds, QGIS®, AR and skyline analysis, 3D format conversion, resources, writing—review and editing, supervision, project administration, and funding acquisition: N.-J.S.; AR software field interaction and skyline analysis: Y.-T.T.; gaming engine simulation: T.-W.H. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflicts of interest.

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