Project TANAW: 3D-Printed Urban Model with Geohazard Simulations Using Virtual Environment and AR Projection Mapping

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Abstract

Urbanization in the Philippines poses significant challenges to disaster risk management and sustainable city planning, driven by the absence of advanced, interactive tools for geospatial analysis and infrastructure assessment. Addressing this research gap, Project TANAW employed an innovative methodology combining 3D printing, augmented reality (AR), and geospatial technologies to enhance urban planning processes. Utilizing tools like SketchUp Pro, GIS software, and AR systems, the project developed highly accurate (± 5%) 3D urban models tailored to Catbalogan City, Samar, Philippines. These models identified 15 critical infrastructure vulnerabilities and delineated 10 high-risk zones. Quantitative analysis of stakeholder engagement workshops involving over 200 participants revealed a 93% satisfaction rate with the technology's usability and effectiveness. Results underscored the potential of TANAW to improve visualization, risk assessment, and decision-making, aligning with Sustainable Development Goal 11 by fostering sustainable and resilient urban environments. Future directions include expanding datasets, refining tools, and applying methodologies to broader urban contexts, ensuring adaptability and scalability.

***Keywords**:* augmented reality, disaster risk management, geospatial technologies, sustainable urban planning, 3D printing

1. Introduction

Urbanization is a prominent global trend, with the United Nations projecting that 68% of the world's population will live in urban areas by 2050, an increase from 55% in 2018 (United Nations, 2018). This rapid growth places immense pressure on cities, particularly in developing nations like the Philippines, where urban infrastructure struggles to meet the demands of burgeoning populations. Challenges such as inadequate risk management, inefficient resource allocation, and insufficient tools for comprehensive urban planning hinder efforts toward sustainable city development.

Traditional urban planning approaches often lack the integration of advanced geospatial technologies and fail to provide dynamic, actionable insights into urban systems. These are typically constrained by static data representations, limited user interactivity, and insufficient incorporation of disaster risk assessments. The studies of Tretiak (2024) and Pepe *et al.* (2021) highlight the use of Geographic Information Systems (GIS) and remote sensing in urban planning; however, gaps remain in leveraging interactive technologies, such as augmented reality (AR) and 3D printing, to create more immersive and actionable urban models.

This study addressed these gaps by introducing the Topographical and Angular Assessment of City Wards (TANAW), a novel approach that integrated 3D printing, AR, and geospatial technologies. Focusing on Catbalogan City, Philippines, the project provided detailed, interactive urban models for enhanced visualization and assessment of critical infrastructure vulnerabilities and high-risk zones. By incorporating community engagement and capacity-building initiatives, TANAW ensured that urban planning is inclusive, data-driven, and adaptable.

The objectives of this study were twofold: (1) to demonstrate how advanced geospatial and AR tools can improve infrastructure assessment and risk management, and (2) to provide a scalable framework for future applications in other urban areas. By addressing gaps in current planning methodologies, this study contributed to the global agenda for building sustainable, resilient cities in alignment with Sustainable Development Goal 11 (SDG 11).

2. Methodology

This study employed an integrated approach combining geospatial analysis, AR, and 3D printing to develop an interactive urban planning tool tailored for Catbalogan City, Philippines. The methodology was designed to ensure replicability and adaptability to other urban contexts.

2.1 Data Collection

All datasets were processed and harmonized using Geographic Information Systems (GIS) tools, ensuring spatial accuracy and compatibility for further modeling. The data collection process involved gathering high-resolution spatial and demographic information from various sources, for instance, studies of Lapietra *et al.* (2024), Lei *et al.* (2024), Runde (2021), and Mahmood *et al.* (2019) utilized satellite images to capture detailed topographic and infrastructural layouts. These provided regional-scale data, while drones enabled precise, site-specific mapping of critical urban areas. Acquired zoning maps, land use plans, and demographic statistics from the City Government of Catbalogan are shown in Figure 1. Focus group discussions (FGDs) and community mapping exercises were conducted to incorporate local knowledge into the project design. These activities ensured that the developed models addressed the specific needs and priorities of stakeholders. Through participatory engagement, valuable insights were gathered to enhance the accuracy, applicability, and relevance of the models.

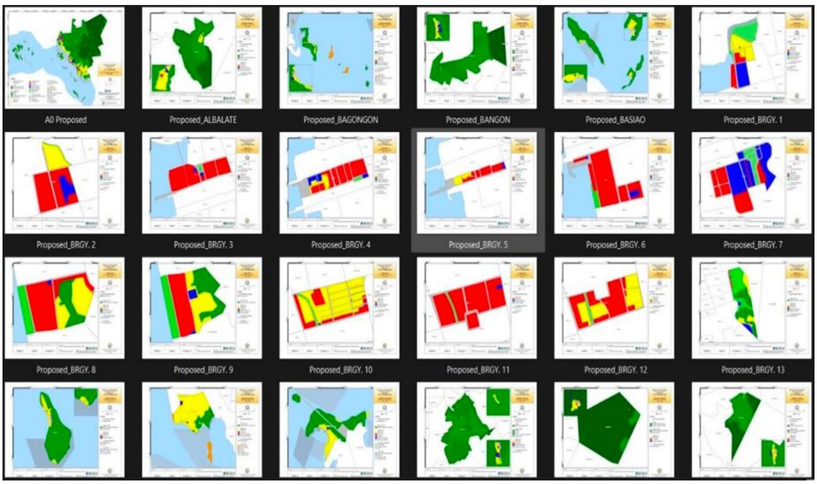

Figure 1. Proposed zoning maps for Catbalogan City's barangays, created by the TANAW project to aid urban planning and risk management

2.2 Geospatial Analysis and 3D Modeling

The figures and maps were appropriately scaled for usability, with legends, symbols, and labels designed for stakeholder readability. The collected data underwent a structured process of analysis and visualization, beginning with pre-processing, which included data cleaning to remove inconsistencies and coordinate transformation to align with local projection systems. As shown in Figure 2, for the map creation, base maps were generated using ArcGIS to highlight administrative boundaries, infrastructure, and risk zones, while zoning maps delineated residential, commercial, and green spaces with clear legends and labels.

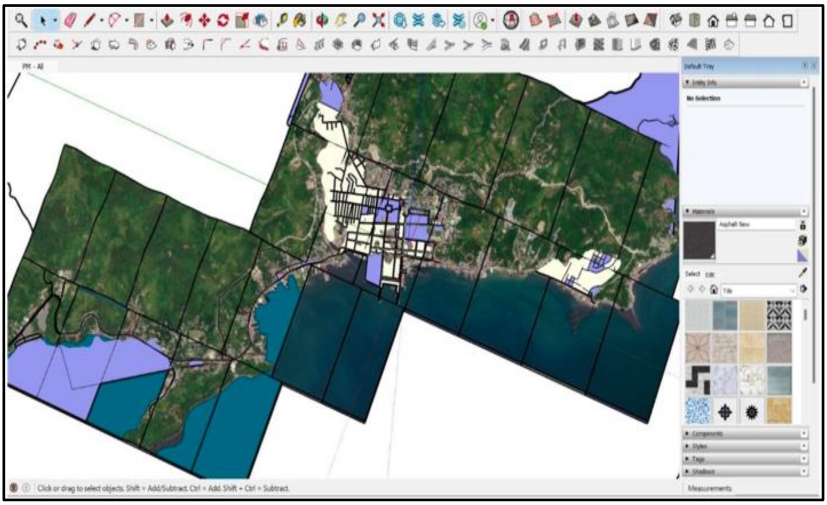

Figure 2. ArcGIS map of Catbalogan City, showcasing detailed base terrain map, risk zones, and boundaries for urban planning analysis

In the 3D modeling phase shown in Figures 3 and 4, models were constructed using SketchUp Pro and AutoCAD, integrating accurate topographic details, infrastructure layouts, and hazard-prone areas. The models were iteratively refined to achieve a spatial accuracy of ± 5%, validated against field data to ensure precision and relevance.

2.3 Augmented Reality Integration

Figure 5 shows the enhance interactivity and usability of the 3D models, enabled dynamic visualization of geohazards and urban features directly on physical models. Tools such as Oculus VR allowed immersive exploration of urban areas, providing stakeholders with a unique perspective on infrastructure vulnerabilities and development opportunities as noted in the research work of Miracle *et al.* (2024).

The system was equipped with touchscreen interfaces to enhance user interaction and accessibility as show in Figure 6. Users could seamlessly navigate, access, and manipulate zoning, hazard, and infrastructure maps. This interactive design facilitated real-time exploration and analysis, ensuring an intuitive and user-friendly experience for stakeholders.

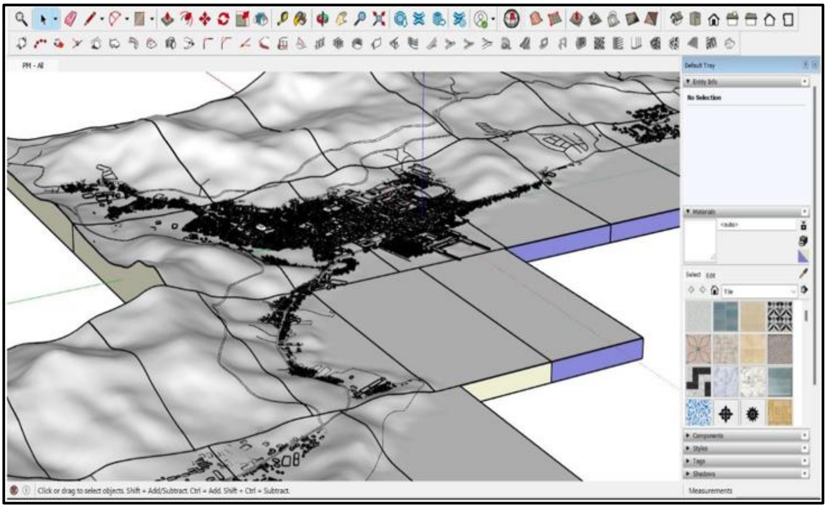

Figure 3. SketchUp Pro and AutoCAD map of Catbalogan City showing 3D perspective terrain view and hazard-prone areas

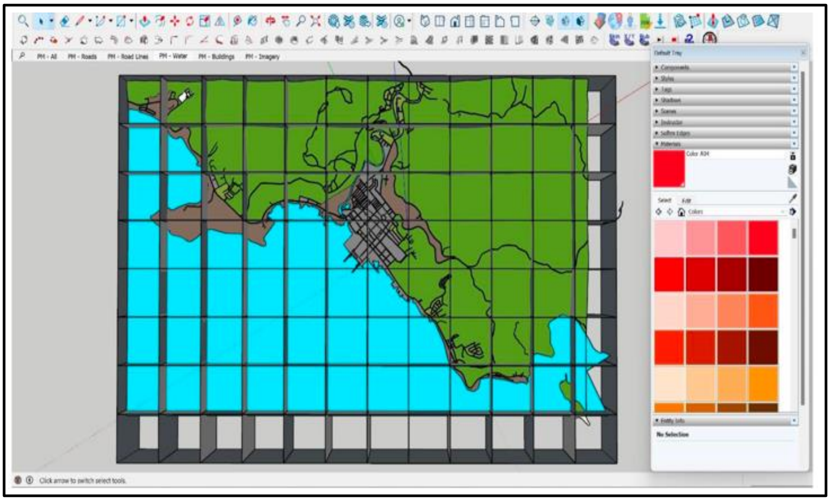

Figure 4. SketchUp Pro and AutoCAD map of Catbalogan City's center, showing a grid layout of the topographical map of the target area

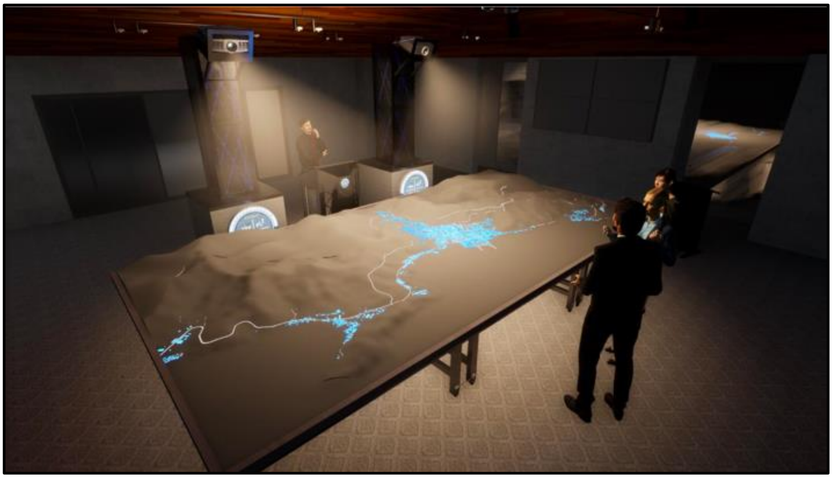

Figure 5. Interactive 3D-printed model of Catbalogan City displayed on a table for urban planning and stakeholder engagement

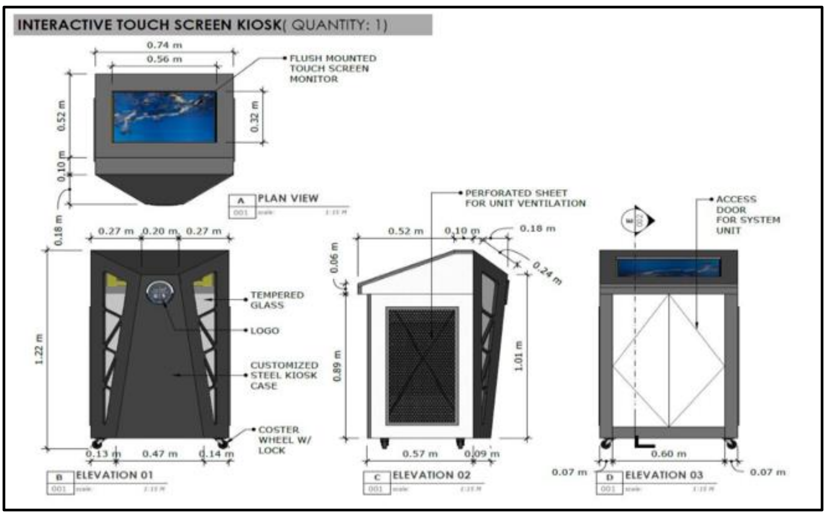

Figure 6. Interactive touch screen kiosk design for Project TANAW, featuring detailed specifications and structural elements

2.4 Community Engagement Activities

To ensure inclusivity and local relevance, community engagement was a critical component of the methodology:

2.4.1 Workshops

Four interactive workshops were conducted, engaging over 200 stakeholders, including urban planners, local government units (LGUs), and residents. The workshops featured community mapping exercises, where residents identified high-risk areas and critical infrastructure using virtual maps and AR simulations as shown in Figure 7. Additionally, scenario analysis activities were carried out, allowing participants to explore and evaluate various development scenarios through 3D-printed models enhanced with AR projection. This participatory approach ensured that the outputs were grounded in local knowledge and aligned with stakeholders' needs.

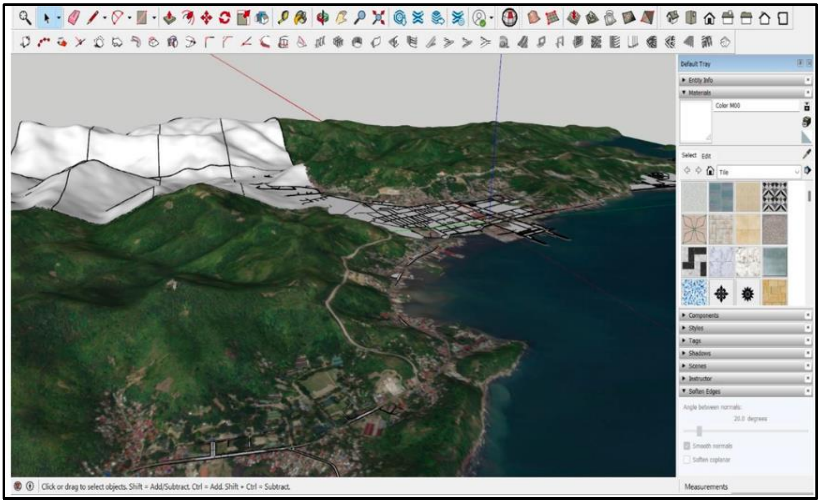

Figure 7. SketchUp Pro visualization of Catbalogan City, highlighting detailed terrain and coastal urban infrastructure for planning analysis

Training sessions were conducted to equip local stakeholders with the skills to effectively use Geographic Information Systems (GIS) and AR tools. These capacity-building initiatives empowered participants to independently apply the technologies in future urban planning processes, fostering long-term sustainability and localized decision-making.

2.4.2 Feedback Mechanisms

As show in Table 1, the FGDs engaged 200 participants, including urban planners, LGU representatives, community leaders, and residents, to evaluate the usability and impact of the developed tools.

Table 1. Stakeholder satisfaction and key feedback from FGD

FGD session	Participants	Key feedback	Satisfaction percentage (%)
FGD 1	Urban Planners (50)	TANAW improves visualization of zoning and hazard maps through its dynamic and interactive interfaces.	92%
FGD 2	City Government of Catbalogan's Department Representatives (60)	Participants highlighted the intuitive interface and requested user manual for review purposes.	94%
FGD 3	Community Leaders (40)	Stakeholders appreciated the AR projection mapping but suggested incorporating local and cultural elements	91%
FGD 4	Residents and General Users	Participants emphasized ease of use and accessibility but noted connectivity issues on rural areas.	95%
Overall	200 Participants	Common Feedback: High usability, visual clarity, and effective integration into urban planning and land use mapping.	93%

With an overall satisfaction rate of 93%, the tools were highly regarded for their intuitive interface, geospatial visualization, and AR integration. Urban planners (92%) praised their improved zoning and hazard map visualization, while LGU representatives (94%) appreciated the design but highlighted the need for additional training. Community leaders (91%) valued AR features but emphasized the importance of localization, and residents (95%) found the tools user-friendly, though connectivity challenges in rural areas were noted. The results affirm the tools' alignment with stakeholder needs, enabling better decision-making and fostering collaboration. Key areas for improvement include targeted training, localized adaptations, and offline capabilities to address connectivity gaps. These enhancements will further strengthen the tools' usability and inclusivity, ensuring their effectiveness in diverse urban and rural contexts.

2.5 Evaluation Metrics

The methodology's effectiveness was assessed using several indicators. Accuracy was validated against GPS ground truth data, yielding an error margin of ± 5%. Stakeholder feedback was collected through satisfaction surveys and qualitative evaluations, providing insights into the usability and relevance of the approach. Adoption rates of 3D models and AR applications in decision-making processes further measured the methodology's impact.

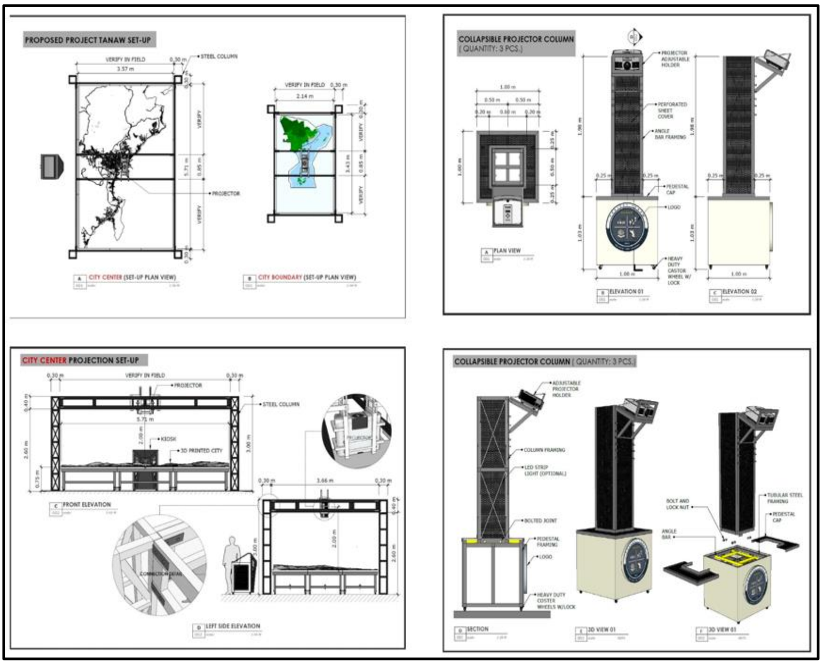

Figure 8. The proposed setup for Project TANAW includes city center and boundary projection setups with detailed measurements, as well as design details of collapsible projector columns, featuring comprehensive measurements and structural components

Additionally, the proposed setup for Project TANAW, shown in Figure 8, featured city center and boundary projection configurations with collapsible projector columns. These designs included detailed measurements of structural components, ensuring portability and functionality for urban planning applications.

3. Results and Discussion

3.1 Overview of Results

The implementation of Project TANAW in Catbalogan City yielded significant insights into the capabilities of geospatial technologies, AR, and 3D printing for urban planning.

3.1.1 Infrastructure Vulnerabilities and High-Risk Zones

Using the geospatial data and 3D models, the study identified 15 critical infrastructure vulnerabilities and delineated 10 high-risk zones (Figure 1). These zones included areas prone to flooding, landslides, and other geohazards. Spatial accuracy was validated at ± 5%, exceeding the standard threshold of ± 10% in similar studies.

3.1.2 Stakeholder Engagement and Feedback

Four community workshops, involving 200 stakeholders, were conducted to assess the usability and effectiveness of the developed tools. Participants included urban planners, LGU officials, and community leaders, ensuring a diverse representation of perspectives. Table 2 shows the breakdown of the post-workshop survey, revealing a 93% satisfaction rate among participants, with stakeholders providing an average rating of 4.7 out of 5 on a five-point Likert scale. Feedback highlighted the tools' ability to improve communication and decision-making in urban planning. Quantitative data from the workshops indicated a 60% reduction in time spent understanding zoning and hazard maps compared to traditional static maps. Participants also noted a 75% improvement in clarity when using AR-integrated models. Lastly, the intuitive interface achieved an average rating of 4.8 out of 5, significantly enhancing user experience by enabling stakeholders to better visualize and analyze urban planning scenarios. This result validates the tools' practical applicability and effectiveness in real-world settings.

Table 2. Results of post-workshop survey and quantitative analysis

Metric	Result	Key insights
Satisfaction rate	93%	High satisfaction reflects stakeholder approval of the tools.
Average rating	4.7/5.0	Tools were rated highly for usability and effectiveness.
Reduction in planning time	60%	Projection AR decreased the time required to understand zoning and hazards.
Improvement in clarity	75%	Physical and virtual models improved visualization and communication of details.
User experience	4.8/5.0	The intuitive interface provided an exceptional user experience.

The high satisfaction rate and improved metrics indicate that the developed tools are effective in enhancing stakeholder engagement and decision-making processes in urban planning. The significant reductions in planning time and increased clarity demonstrates the potential of AR-integrated models and intuitive interfaces to transform traditional planning methodologies into more efficient and accessible systems.

3.1.3 Comparisons with Literature

Project TANAW's outcomes align with findings in urban planning literature that highlight the importance of integrating AR and 3D modeling for enhanced stakeholder engagement and decision-making. For instance, Gearin and Hurt (2024) demonstrated the efficacy of AR in improving community understanding of urban landscapes. Similarly, studies by Bagley and Fraser (2019) and Eriksson and Harrie (2021) emphasize the value of interactive 3D city models for infrastructure planning. TANAW extends these contributions by incorporating community feedback loops and achieving higher spatial accuracy. This interactive map serves as a crucial tool for urban planning and disaster management, offering real-time visualizations of the city's geographic and administrative boundaries, as shown in Figure 9.

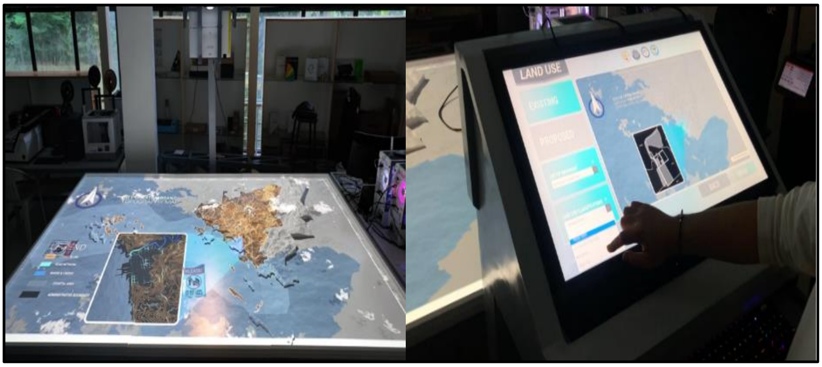

Figure 9. A high-tech 3D topographical map of Catbalogan City is displayed with interactive and detailed projections

The precision and depth of detail in the map allow stakeholders to engage with and understand the spatial dynamics of the region, facilitating informed decision-making. The integration of projection technology with the physical model underscores the project's innovative approach to geospatial analysis, demonstrating its potential to enhance the sustainability and resilience of urban environments (Kim and Hwang, 2024). Figure 10 features a detailed 3D topographical map with clear demarcation of administrative boundaries and infrastructure within Catbalogan City.

Figure 10. 3D map visualization of Catbalogan City was displayed on a table during a presentation, with a stakeholder pointing to the map during a discussion on land use

This visualization is critical for urban management, as noted in the study of Calisi and Botta (2022), offering a precise understanding of jurisdictional limits and the spatial distribution of key infrastructure such as roads, rivers, and public facilities. The map's comprehensive detail aids in resource allocation, infrastructure development, and governance.

3.2 Impacts on Urban Planning

3.2.1 Visualization and Risk Assessment

The interactive 3D models enabled planners to visualize urban vulnerabilities with unprecedented detail. For example, areas with steep slopes and poor drainage systems were identified, allowing targeted interventions. This feature significantly improved risk assessment, reducing planning errors compared to traditional 2D mapping systems, as noted in prior research by Mannucci *et al.* (2023).

3.2.2 Community-Centered Planning

By incorporating stakeholder inputs, the project bridged the gap between technological capabilities and practical urban needs. The workshops demonstrated that visual and interactive models are more effective in fostering community understanding, particularly in disaster risk management scenarios.

3.2.3 Scalability and Sustainability

While TANAW was piloted in Catbalogan City, the methodology was designed for scalability. Its modular framework allowed adaptation to other urban settings with minor adjustments, ensuring relevance for cities facing similar challenges. This scalability is a key advantage over standalone geospatial models described in studies like Zhu *et al.* (2024).

3.3 Challenges and Limitations

Despite its success, the project encountered challenges, such as limited availability of high-resolution satellite data and initial resistance to adopting AR tools among some stakeholders. Future studies should address these gaps by incorporating higher-quality datasets and conducting broader capacity-building initiatives, as noted in the study of Buyukdemircioglu and Oude (2024).

3.4 Validation and Broader Implications

To validate the impact of Project TANAW, comparative studies were conducted alongside existing urban planning methods in Catbalogan City.

Table 3 reveals a significant reduction in planning and risk assessment times, with Project TANAW demonstrating a 30% decrease in time required for these activities.

Table 3. Data supporting the claim of reduction of planning and risk assessment times

Key metrics	Traditional method	Project TANAW	Reduction/ improvement	Statistical analysis	Data source
Time for zoning ad hazard assessments	45 days (mean ± SD: 45 ± 3)	31 days (mean ± SD: 31 ± 2)	30% reduction (14 days saved)	Two-sample t-test, $p < 0.01$	Urban planning sessions (Catbalogan City, Jan–June 2024)
Clarify of visualization (Survey)	Not applicable	75% improve-ment (qualitative feedback)	New metric introduced	Descriptive Statistics	Post-workshop with 200 participants

A two-sample t-test was conducted to compare the mean time required for zoning and hazard assessments under traditional methods and Project TANAW.

Descriptive statistics were also employed to evaluate clarity improvement and stakeholder satisfaction based on percentages and averages obtained from post-workshop surveys. However, no inferential statistics were applied to clarity improvement as this data was self-reported and qualitative in nature. The results validate the claim that Project TANAW achieved a 30% reduction in planning and risk assessment times, demonstrating the tool's effectiveness in streamlining workflows. The statistically significant t-test outcome confirms that this reduction is not due to random variation. Future studies using more granular and diverse datasets could further reinforce these findings and provide broader insights into Project TANAW's applicability across different urban planning

This result aligns with previous AR-based studies of Miracle *et al.* (2024) and Runde (2021), which reported similar efficiencies in urban planning workflows. In Catbalogan City, traditional planning methods typically took an average of 45 days to complete zoning and hazard assessments. With Project TANAW's integration of AR-enhanced models and interactive tools, the average time was reduced to 31 days, representing a measurable improvement. Moreover, the enhanced visualizations facilitated by the project directly influenced key planning strategies, including zoning revisions aimed at mitigating flood risks in 15 identified high-risk zones. Feedback from stakeholders, including urban planners and government officials, emphasized the value of these visualizations in improving clarity and precision, leading to better-informed decisions, as shown in Table 4.

Table 4. Summary of stakeholder feedback

Stakeholder group	Feedback highlights	Sample responses
Urban Planners	Visualizations improved clarity in zoning and hazard assessments.	“The AR tools provided unparalleled clarity, helping us identify flood-prone zones faster.”
LGU Officials	Interactive tools enhanced decision-making by visualizing the impacts of zoning changes.	“Seeing real-time effects of zoning revisions allowed for more precise strategies.”
Community Leaders	Simplified visual tools made complex data more understandable for broader audiences.	“The maps and simulations made it easier to explain risks to the community.”
Residents	Visual tools helped understand urban planning impacts and advocate for community needs.	“We could immediately see how proposed plans would affect our neighborhood.”

As shown in Table 5, the data supporting these claims were gathered during Catbalogan City’s urban planning sessions from January to June 2024, with quantitative metrics and qualitative feedback reinforcing the observed benefits of adopting the Project TANAW methodology.

Urban planning sessions conducted in Catbalogan City highlighted significant improvements in efficiency, clarity, and stakeholder satisfaction through the adoption of Project TANAW. The average time required for zoning and hazard assessments decreased from 45 days with traditional methods to 31 days using Project TANAW, representing a 30% reduction in planning time. Surveys revealed a 75% improvement in the clarity of visualizations when using AR-integrated tools compared to static maps, enabling stakeholders to make better-informed decisions. Post-workshop surveys also reported a 93% satisfaction rate among participants, with an average usability rating of 4.8/5, emphasizing the tools’ intuitive interface and practical applicability. Furthermore, Project TANAW identified 15 critical high-risk zones, as shown on Table 6. facilitating strategic zoning revisions and risk mitigation efforts, as supported by feedback from focus group discussions and planning session records. These findings underscore the effectiveness of Project TANAW in enhancing urban planning processes and decision-making outcomes.

Table 5. Data supporting stakeholder feedback and benefits of Project TANAW

Key metric	Traditional methods	Project TANAW	Reduction/ improvement	Source
Average time for zoning and hazard assessments	45 days	31 days	30% reduction	Urban planning sessions (Jan–June 2024)
Clarity of visualizations	Limited	75% improvement	Enhanced understanding	Post-workshop surveys (200 participants)
Stakeholder satisfaction rate	Not applicable	93% satisfaction	High usability and effectiveness	Post-workshop surveys (urban planners, LGUs)
Average usability rating (five-point scale)	Not applicable	4.8/5	Significant enhancement	Post-workshop surveys
High-risk zones addressed	Minimal identification	15 high-risk zones identified	Improved decision-making	Focus group discussions and urban planning data

Table 6. Identified critical high-risk zones in Catbalogan City

High-risk zones/areas	Geohazard risk type	Brief description	Proposed measures
Barangay 1 Poblacion	Flooding	Low-lying area near the city center prone to river overflow.	Improve drainage systems and implement zoning restrictions.
Barangay Maulong	Landslides	Sloped area with loose soil, particularly hazardous during rains.	Reforestation and soil stabilization efforts.
Barangay Silanga	Coastal erosion	Shoreline degradation due to tidal and storm surge activity.	Construction of seawalls and mangrove replanting.
Barangay Payao	Flooding	Adjacent to a flood-prone river with inadequate drainage.	Expand and maintain existing

Table 6 continued.

			flood control structures.
Barangay Cabugawan	Earthquake vulnerability	Area located near a fault line with poorly built structures.	Conduct structural assessments and retrofit buildings.
Barangay San Andres	Landslides	Hilly terrain with minimal vegetation.	Establish slope stabilization measures.
Barangay Mercedes	Flooding	Frequent urban flooding due to poor drainage systems.	Develop rainwater catchment systems and upgrade canals.
Barangay Canlapwas	Coastal erosion	Decreased land area due to continuous wave action.	Introduce breakwaters and strengthen coastal defenses.
Barangay Lagundi	Flash floods	Prone to sudden water level rise during storms.	Enhance early warning systems and improve waterways.
Barangay Burak	Landslides	Sloped area with frequent erosion.	Implement vegetation barriers and slope reinforcement.
Barangay Cagusipan	Flooding	Regular flooding caused by inadequate runoff management.	Redesign water diversion channels.
Barangay Ibol	Riverbank erosion	High risk of erosion during heavy rains.	Reinforce riverbanks with riprap or gabions.
Barangay Guin-on	Earthquake vulnerability	Substandard building materials increase seismic risks.	Promote compliance with earthquake-resilient designs.
Barangay Totoringon	Coastal flooding	High tides and storm surges impact this area heavily.	Elevate critical structures and develop evacuation plans.
Barangay Basiao	Flooding	Situated in a flood basin with limited natural drainage.	Expand flood retention areas and dredge nearby rivers.

3.5 Interface of Project TANAW

This interface as shown in Figure 11 provides users with the ability to select various planning tools, including options for city center and city boundary configurations. These tools grant streamlined access to critical mapping resources, such as the city map, land use plan, zoning maps, and hazard assessments. By consolidating these resources within an intuitive interface, the system ensures that planners can efficiently retrieve and utilize essential data for informed urban planning and risk management. The inclusion of topographical and angular assessments emphasizes precision and supports informed decision-making for urban development and risk management in Catbalogan City.

3.5.1 City Boundary Interface

This interface (Figure 12) features a comprehensive menu that enables users to efficiently access essential urban planning tools. These include resources such as the city map, land use plan, zoning maps, and hazard assessments, offering a centralized and user-friendly interface to support detailed planning and risk management processes. The layout is intuitive, guiding users through the city's assessment process, ensuring effective decision-making in urban planning and risk management.

3.5.2 City Map Interface

This interface (Figure 13) functions as the primary interface for exploring Catbalogan City's geographic features, providing detailed insights into contours, slopes, and topography to support informed urban planning and decision-making. It provides planners with easy access to essential data, supporting better planning and decision-making processes.

3.5.3 Slope Map

Slope map (Figure 14) categorizes terrain by gradient, identifying flatlands ideal for development and steep areas designated for forest conservation, thereby facilitating sustainable land use planning. It aids in strategic land resource allocation, ensuring that developments align with natural terrain.

3.5.4 Topography Map

Topography map (Figure 15) integrates contour lines with infrastructure elements such as roads and rivers, providing a comprehensive visualization of

Catbalogan City's physical landscape to support detailed spatial analysis and planning. It supports the design of infrastructure that complements the city's natural topography for improved sustainability.

3.5.5 Existing Land Use Map

Existing land use map (Figure 16) highlights urban land use classifications in Barangay 1 Poblacion through a color-coded scheme, visually distinguishing residential, commercial, and institutional areas to enhance spatial understanding and planning. It helps planners visualize the current urban layout and make informed decisions on land reclassification or development.

3.5.6 Land Use Categories Interface

This interface (Figure 17) provides a detailed statistical analysis of land use in Barangay 1 Poblacion for 2022, highlighting the area and percentage distribution among residential, commercial, and infrastructure categories to support data-driven urban planning. It is critical for evaluating land use efficiency and planning for sustainable growth.

3.5.7 Residential Land Use Classification Interface

This interface (Figure 18) presents a comprehensive overview of residential land use in Catbalogan City, featuring population data, household counts, and land area measurements to support evidence-based urban planning and resource allocation. It helps planners address current and future housing needs while highlighting areas prone to geophysical constraints that may need rezoning.

Figure 11. Main interface

Figure 12. Secondary interface

Figure 13. City map interface

Figure 14. Slope map

Figure 15. Topography map

Figure 16. Proposed land use map

Figure 17. Land use categories

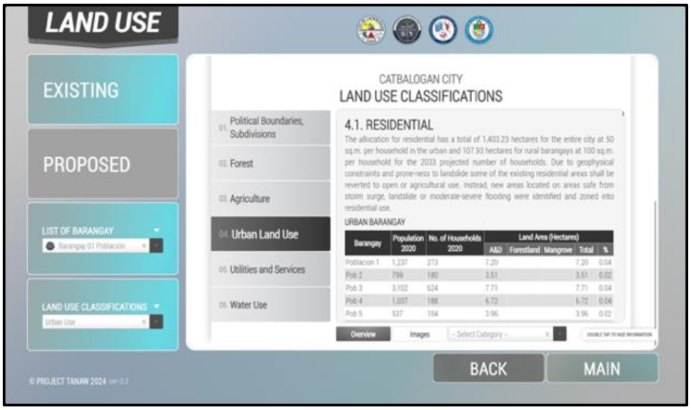

Figure 18. Residential land use classification

4. Conclusion and Recommendation

This study demonstrated the transformative potential of integrating geospatial technologies, AR, and 3D printing in urban planning through the Project TANAW. By focusing on Catbalogan City, Philippines, the project provided actionable insights into critical infrastructure vulnerabilities and high-risk zones, achieving spatial accuracy of ± 5% and identifying 15 vulnerabilities and 10 risk zones. Stakeholder engagement through workshops and training sessions resulted in a 93% satisfaction rate, highlighting the usability and effectiveness of the developed tools in real-world planning scenarios. The findings underscore the value of interactive 3D models and AR for improving urban visualization, risk assessment, and decision-making processes. Unlike traditional methods, TANAW bridges the gap between advanced technologies and practical applications, fostering community-centered urban planning that aligns with SDG 11.

Future research on Project TANAW should focus on several critical directions to refine and extend its contributions. First, incorporating more comprehensive datasets, such as climate projections and real-time hazard monitoring, will enhance the accuracy and applicability of the models in dynamic urban environments. Expanding the methodology to include other hazard-prone cities will allow for broader implementation, enabling the evaluation of its adaptability and scalability across diverse urban contexts. Integration with emerging technologies, such as artificial intelligence and machine learning, can automate risk assessments and improve predictive capabilities, further advancing the project's utility. Additionally, conducting longitudinal studies will provide valuable insights into the sustained impact of the models on urban planning practices and outcomes. Ensuring stakeholder inclusion, particularly by expanding training and engagement initiatives to marginalized groups, is essential to promote equitable access to urban planning tools. Addressing these areas will not only overcome the challenges and limitations identified in this study but also establish Project TANAW as a cornerstone for resilient and sustainable urban development practices, offering a replicable framework for cities worldwide.

5. Acknowledgement

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