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Exploring the Digitalization of Historic Buildings for Urban Heritage Governance in Kayutangan Heritage Malang, Indonesia

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Herry Santosa[1], Fauzul Rizal Sutikno[2], Adipandang Yudono[3], Muhammad Satya Adhitama[4], Eni Zuliana[5]
1,4,5 Architecture Department, Faculty of Engineering, Brawijaya University, Indonesia
herrysantosa@ub.ac.id
2,3 Urban Regional and Planning Department, Faculty of Engineering, Brawijaya University, Indonesia

Abstract

Digital technology is significantly transforming the documentation, analysis, and preservation of historic buildings from the past. The recent development of digital tools and techniques can be helpful for various activities such as documentation, monitoring, and decision-making processes. An in-depth study of the advantages and disadvantages of digitalization highlights the importance of integrating digital approaches into urban cultural heritage governance practices. This paper aims to explore advances in digitalization tools, focusing on the Kayutangan heritage in Malang, Indonesia, highlighting the importance of incorporating virtual tourism through precision and accuracy in visual data mining and enriching the diversity of uses of the latest digital technology. These innovations cover many aspects, including the art of complex 3D modeling applied to historical editions, the creative fields of virtual reality and augmented reality and progressive developments in Metaverse technology. This study also points out the strengths and weaknesses of various types of digital technology development in historic buildings and areas. Eventually, this study emphasizes implementing a web-based Kayutangan digital heritage information system integrated with the Metaverse gateway and complemented by a comprehensive user assessment survey to improve the overall user experience. This study unveils a favorable public assessment regarding the Kayutangan Metaverse development and, all at once, strengthens efforts in advancing smart governance innovations for managing the historic Kayutangan area. The findings from user assessment questionnaires and analysis calculations indicate that the development of Kayutangan Metaverse technology is highly rated. Furthermore, it is essential to focus on enhancing the representation of individuals and objects, improving virtual surroundings, and increasing the accessibility of human-related information content in such environments.

Keywords: digitalization; governance; historic buildings; kayutangan heritage; preservation.

1. Introduction

Preserving historic buildings involves careful repair and restoration, protective treatments, and ongoing maintenance to keep the facility in continuing use while maintaining its authenticity and historic character (Noor Azizu et al., 2011). Digitalization technology is vital in conservation efforts for cultural heritage buildings. Digital technology enables a more comprehensive and precise recording of historical buildings. Reality technologies like 360-degree cameras, virtual reality, and augmented reality permit the public to virtually visit and explore cultural heritage buildings while preserving the original physical structure. This digitalization process facilitates the creation of virtual tours and 3D models accessible to a broader audience. Consequently, it allows more individuals to experience historic buildings without physical visits.

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The latest technological developments in recording physical data on historic buildings, such as laser scanning and photogrammetry, allow the creation of 3D models that serve as virtual replicas of physical structures (Murphy & King, 2016). Through interactive websites, virtual tours, and augmented reality applications, people worldwide can explore and experience historic buildings remotely. Moreover, sensor networks and data analysis tools can identify alterations in environmental factors like temperature, humidity, and air quality, which can impact damage to building materials. The abundant digital repositories and database availability will provide a platform for sharing research findings, best practices, and conservation techniques (Murphy & King, 2016). Furthermore, collaborative projects digitize shared heritage sites, encourage cultural exchange, and enable knowledge transfer between countries and institutions (Megantara et al., 2015).

The advantages of 3D modeling are that it can help assess a building (Trisyanti et al., 2023). It can absorb all existing information into 3D structural modeling (Tytarenko et al., 2023) to make ordinary people understand and be more interested in building more deeply (Liu et al., 2023) and help people get to know the building (Panou et al., 2018). 3D-GIS tests the shape and height of buildings against the horizon. 4D modeling building technology is currently used as a source of information for reconstructing historical buildings (Farella et al., 2021). A study states that 3D modeling is effective for all building cases (Bach et al., 2018) and detailing (Lo Brutto et al., 2017). This method has proven easy, simple, fast, and effective (Koeva, 2016). Conservation using spatial mapping (Teruggi & Fassi, 2022), 3D modeling, and drone surveys have proven effective (D'Aprile & Piscitelli, 2019).

On the other hand, the development of renewable technology can improve conservation efforts (Di Paola et al., 2017), and augmented reality is a technological innovation used for planning and arranging buildings, as well as to drive the economy around the area by making augmented reality a guide for visitors (Panou et al., 2018). The prototype shapes the building to generate augmented reality over the building area. Renewable LiDAR technology functions to measure and document buildings; combining LIDAR with UAVs will be more effective and accurate (Chiabrando et al., 2017). Structure for motion (SfM) is an alternative to laser scanners (Al Khalil, 2020). It is also a renewable technology used to collect information about buildings accurately. 3D point clouds can provide detailed and accurate building information (Herban et al., 2022). Terrestrial Laser Scanning (TSL) and Long-Range Aircraft Systems (RPAS) are methods used to create accurate 3D modeling (Lo Brutto et al., 2018). Unmanned Aerial Systems (UAS) are used to improve conservation efforts for historic buildings effectively, quickly, cheaply, and accurately (Lo Brutto et al., 2017) (Gagliolo et al., 2017). 3D virtual tours aim to influence the general public to be interested in cultural heritage buildings and as an effort to restore or preserve damaged parts of buildings (Elbshbeshi et al., 2023).

Recent advances in digital technology have proved and revolutionized how communities preserve and access the cultural heritage contained in historic buildings. Digitalization has emerged as a powerful tool for documenting, analyzing, and disseminating information about these architectural treasures. Laser scanning, photogrammetry, and virtual and augmented reality offer new documentation, interpretation, and avenues of public engagement. Digitalization increases our understanding of historic buildings, facilitates research, conservation, and restoration efforts, and enables inclusive access for diverse audiences. Leveraging these digital tools ensures the continued preservation and celebration of shared cultural heritage. Ultimately, digital documentation and archiving have become essential components of the digitalization process (Thwaites et al., 2019). The app offers virtual tours, interactive maps, augmented reality experiences, and curated information about the building's history and significance. These digital platforms allow visitors to customize their experience, increasing their understanding and appreciation of cultural heritage. Digitalization has democratized access to historic buildings and cultural heritage. Online platforms, virtual tours, and digital exhibitions provide inclusive access to people who cannot physically visit the building due to geographic, socio-economic, or physical barriers. This more comprehensive access encourages inclusivity, cultural exchange, and increased appreciation of diverse heritage worldwide (Susanna et al., 2021). Hence, the most prominent issues and challenges are the importance of the digital transformation of government and entrepreneurial governance (innovative governance) in managing regional assets and historical buildings, which have the opportunity to build a historical tourism industry. Digital innovation of building assets or historical areas transforms the tourism management concept into online virtual tour models with a historical tourism adventure concept offering a virtual exploration of tourism experiences.

Kayutangan is one of the prospective historical areas in Malang, Indonesia, which has the potential to develop into a tourism business through digital innovation towards sustainable business and tourism (e-commerce). Kayutangan, Malang's capital of urban heritage, is a vibrant urban area with a rich cultural and historical heritage with its architectural significance, cultural identity, community engagement, and economic contributions. Kayutangan is renowned for its distinctive architectural styles, blending colonial, traditional Javanese, and Chinese influences (Santosa et al., 2015). The area features well-preserved Dutch colonial-era buildings with intricate facades, ornate details, and unique architectural elements. These buildings contribute to the visual appeal of Kayutangan but also serve as important historical markers, illustrating the city's past and architectural evolution. Kayutangan plays a crucial role in preserving and promoting Malang's cultural identity. The area is known for its traditional markets, art galleries, and cultural events celebrating local traditions and heritage. The community takes pride in preserving its cultural practices, including traditional music, dance, and culinary arts, which are showcased in various cultural festivals and events. Kayutangan serves as a living testament to Malang's cultural diversity and richness. Preserving and promoting Kayutangan's urban heritage requires a collaborative effort from various stakeholders to ensure sustainable management and responsible tourism. By recognizing the value of Kayutangan's heritage, the community and government can secure a prosperous future of digital innovation in tourism management while safeguarding the unique urban heritage.

In the Kayutangan Heritage area, digitalization efforts have encompassed 3D modeling, decision support system (DSS) modeling, HBIM, Photo and Modeling 360°, Virtual Reality, and Augmented Reality. Nevertheless, limited research has explored the development of virtual tours utilizing metaverse technology. Therefore, this study aims to explore advances in digitalization tools, focusing on the Kayutangan heritage in Malang, Indonesia, highlighting the importance of incorporating virtual tourism through precision and accuracy in visual data mining and enriching the diversity of uses of the latest digital technology.

2. Theoretical Framework

2.1 Research Location

This research will focus on developing sustainability practices in heritage sites. The Kayutangan heritage area is rich in cultural heritage, such as Dutch fortifications and colonial architecture, which are ideal for studying sustainable development goals and regulations. The Kayutangan area in Malang City, designated as a Malang City Cultural Heritage area, is an important trade and service corridor built during the Dutch colonial era. Three key Dutch East Indies architectural style advancements can be seen in this region, notably the Indische Empire style (1850–1900), the early modern colonial style (1900–1915), and the Nieuwe Bouwen style (1916–1940). The Kayutangan historical area has many well-preserved historical buildings from the Dutch colonial heritage, which have the potential to become historical tourist attractions. Since the Dutch colonial era, the Kayutangan road corridor has been an essential trade road access connecting Malang City Square with Surabaya City. In addition, corridors provide an ideal overview of how to carry out sustainable tourism destination development, making them ideal research locations.

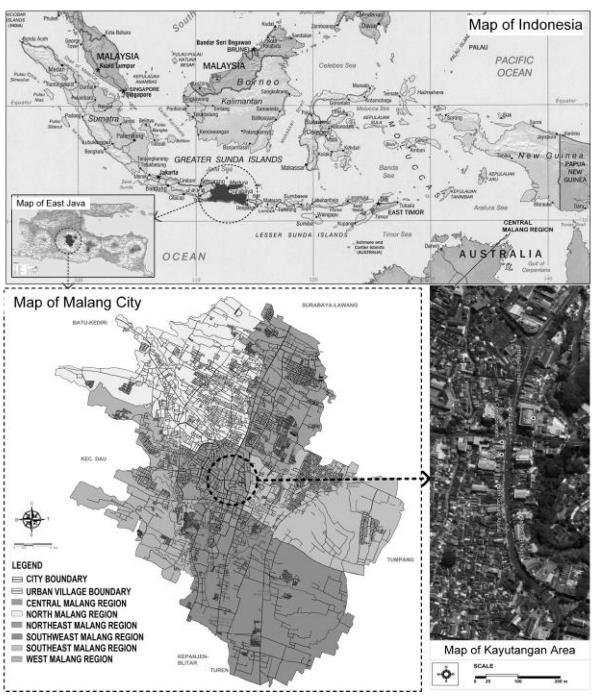

Figure 1. Map of Kayutangan area, Malang, Indonesia

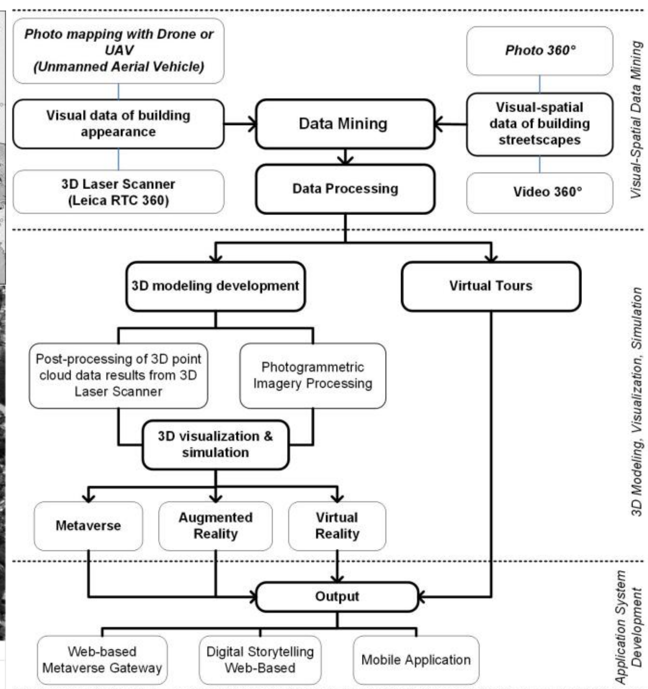

Figure 2. Diagram of the digitalization development method for the Kayutangan heritage

2.2 Method

This study examines the three parts of digitization methods in the Kayutangan area (see Figure 1), namely visual-spatial data mining, 3D modeling, visualization, simulation, and application system development, as shown in the diagram of the digitalization development method for the Kayutangan historic area (Figure 2.)

The first stage focuses on visualization and modeling, which are essential as the basis for developing regional digitalization (Gonizzi Barsanti et al., 2015). Kayutangan 3D Modeling uses 3D software to create a 3D model of the Kayutangan area. The required data is visual data of building appearance and visual-spatial data of building streetscapes. Visual recording of building appearance data uses a UAV and 3D laser scanner while recording visual spatial data of building streetscapes uses photo 360 and video 360 technology. The second stage is process data, which includes 3D modeling, visualization, and simulation. Process data consists of post-processing of 3D point cloud data resulting from 3D Laser Scanner and photogrammetric imagery processing, which produces 3D visualization and simulation in the form of Metaverse, augmented reality, virtual reality, and virtual tours. The third stage is application system development. 3D modeling, visualization, and simulation results are applied to web-based metaverse gateways, web-based digital storytelling, and mobile applications.

This model will create a decision support system (DSS) to help stakeholders analyze the consequences of implementing various alternatives to improve the landscape. Second, the Decision Support System Model uses computer software to systematically evaluate and analyze decision alternatives based on predetermined criteria such as cost, time, and stakeholder input. Third, HBIM combines LiDAR technology (Ma, 2021), BIM, video, and other data collected using drones into one 3D data set.

This data set can produce a comprehensive 3D digital model of the Kayutangan area. This model uses several applications, including virtual reality experiences, augmented reality applications, and 3D printing. Fourth, Photo and Modeling 360 combines 360-degree photos taken from the Kayutangan area and 3D models produced using the HBIM data set. Fifth, Augmented Reality technology combines 3D models generated using the HBIM data set with visualization in graphic overlays on real-world displays. Furthermore, Metaverse technology combines 3D reality with an online platform. Metaverse allows stakeholders to access 3D models generated from HBIM datasets via a cloud platform. Metaverse can be implemented for virtual reality applications.

Data mining plays a fundamental role in research by providing the data and information necessary to conduct research, analyze trends, validate hypotheses, and generate new knowledge. Data mining on the Geo-Historic Urban application system development method based on the Digital Platform for Urban Heritage Management, or what is familiarly called 3D Spatial Interactive Multimedia (3D SIM), is closely related to developing 3D visualization scenarios as a guide. For the concept of developing 3D simulations, which includes six foundations for creating 3D modeling visualizations, namely: (1) Identification of primary and secondary building elements, (2) Determination of 3D object types, (3) Optimization of 3D geometry, (4) Mapping of textures and images, (5) Division public and private zones, (6) Determination of interactive variables (changes in position, changes in height, and changes in texture or image).

Data mining in Information Modeling of Cultural Heritage Buildings (HBIM) is developing a spatial multimedia system concept based on Data Interactivity and BIG DATA management for cultural heritage preservation (Mezzino et al., 2017). This stage is related to the automatic reconstruction process of 3D object models of historic buildings, which includes three stages, namely (1) Developing the concept of an HBIM-based spatial multimedia system, (2) Identification and visual Data Recording of Historical Buildings, (3) Visual Modeling of BIM-Based Historical Buildings. The equipment includes GPS, Laser Scanning, Digital Meter Logger, and Digital Cameras. Data mining virtual tourism data based on augmented reality and story maps related to the automatic reconstruction process of 3D object models of historic buildings includes three activities, namely (1) Developing a strategy for the concept of Virtual Tourism applications on Spatial Multimedia Systems Based on Augmented Reality technology and Web GIS Story Maps, (2) Identification & Recording of Visual Data on Historical Landmark Buildings, (3) HBIM Based Historical Building Reconstruction Process. The equipment used includes GPS, Laser Scanning, and Digital Cameras.

Mining data on the development of the Metaverse is by mapping, recording, and visual reconstruction of buildings in the historic area of the Jalan Kayutangan corridor. This stage is related to the process of automatic reconstruction of 3D object models of historical buildings, which includes 3 (three) activities, namely (1) Formulation of the Historical Area Metaverse Prototype concept strategy to Build a Spatial Public Engagement System Based on Digital Immersive Experiences, (2) Identification & Recording of Visual Data Historic buildings along the corridor, (3) HBIM-based historical building reconstruction process. The equipment used includes GPS, Laser Scanning, and Digital Cameras.

Data processing in 3D Spatial Interactive Multimedia (3D SIM) aims to develop an integration of 3D visualization of historical buildings and areas with a GIS data reference system, followed by developing web-based spatial multimedia system application programming (online system). The data processing process on the development of the Heritage Building Information Modeling (HBIM) tool aims to develop the integration of 3D data on historic buildings on the Spatial Multimedia system and the HBIM system. This stage is related to the process of integration and processing of the reconstruction of 3D objects of historic buildings with the help of BIM-based software, followed by the process of developing web-based spatial multimedia system applications (online systems). This stage relates to the web application development process integrated with all HBIM data.

The data processing in augmented reality and story map-based virtual tourism aims to develop spatial models for virtual and augmented reality with the assistance of BIM-based software, including three activities, namely (1) development of basic modeling of historic landmark buildings, (2) development of spatial modeling Virtual Reality (3) Development of Augmented Reality technology devices. The software includes photogrammetry, 3D models (BIM), and ArcGIS. Then, the programming process of developing a web-based spatial multimedia application (online system) will be conducted through the Web GIS-based Story Maps application. This stage relates to developing the Story Maps application, which is integrated with Augmented Reality technology and contains all types of spatial modeling data.

The data processing in metaverse development aims to develop a Virtual Reality modeling database through three activities, namely, (1) Development of basic modeling of Historical Areas, (2) Development of Virtual Reality spatial modeling, (3) Development of Extended Reality (XR) technology devices. The software includes photogrammetry, 3D models (BIM), and ArcGIS. The next stage is to develop a web-based Metaverse environment (online system) and accommodate Immersive Digital Experiences. This stage includes 3 (three) main activities, namely (1) Integration of animated data and 3D VR Historical Buildings on the application system, (2) Final programming of the UID spatial immersive multimedia system, (3) Development of the Metaverse Prototype of Historical Areas of City Poor Corridors Kayutangan. The device used is Unity 3D software (Zhang, 2022).

This research on the digitization of the Kayutangan historic building resulted in three software products: a web-based metaverse gateway, digital web-based storytelling, and mobile applications. Metaverse gateway is a web-based platform or portal that allows users to access and interact with Metaverse via a web browser. The advantage of web-based Metaverse Gateway is its easy accessibility. Users do not need to download or install a particular application to enter Metaverse but only use a web browser that is generally available on their device. This ease of use makes the Metaverse more open and accessible to more people. Web-based digital storytelling about the Kayutangan Historic Building is a form of digital narrative that uses web media to reveal and describe the rich history and culture of the Kayutangan Historic Building. Access the Kayutangan Historical Building mobile application via smartphone or tablet. It aims to provide users with interactive, educational, and exciting information and experiences about the Kayutangan Historical Building. These applications can be downloaded and installed on users' devices through application stores such as Google Play Store or Apple App Store.

This study specifically evaluates the development of the latest digitalization system, namely Metaverse. The questionnaires were evaluated by distributing questionnaires at the exhibition held at the MCC (Malang Creative Center), and respondents used the metaverse tool during the metaverse prototype trial. The trial aims to measure how users understand and add to their knowledge about the Kayutangan Historical Buildings through the metaverse application. The community's assessment of the Kayutangan metaverse can be measured by checking whether users can correctly identify critical information, understand the historical context, or describe architectural elements after using the application. Measuring user interaction is essential for understanding the effectiveness and success of metaverse applications. The data and feedback obtained from this trial are capital for making improvements and further development and ensuring that the application meets the expectations and needs of users.

Participants and stimuli to study different and possibly conflicting inputs from the Metaverse of the Kayutangan region among different groups of people, namely students, practitioners from various scientific fields, and government workers, and to enable statistical generalizations for similar populations living in and visiting heritage tourism sites elsewhere in developing countries; respondents are of working age. Aged between 16-65 years who lived in or had visited Kayutangan were randomly selected. A random sample of 32 tourists is selected. The stimuli to the respondents in this study were buildings along the Kayutangan corridor in the metaverse version.

Table 1. Research variables

No.	Variable	Sub variable
1.	General assessment	1. System performance
		2. System Understanding
		3. System Usability
2.	Operation of the system	1. System response speed
3.	Quality of visualization	1. Text Quality
		2. Human and Object Visualization Quality
		3. Virtual Environment Quality
4.	Quality of user interaction	1. Floating Panel Interaction Quality
		2. Availability of Information Content
		3. Diversity of Application Features

This research performed the metaverse tool using four variables and ten sub-variables selected and taken based on previous research (see Table 1.). This study selects variables based on suitability for the research area, namely Kayutangan, namely, general assessment, operation of the system, quality of visualization, quality of user interaction, and sub-variables, namely, application quality, application understanding, availability of instructions, application speed, writing quality, visual quality of objects and people, virtual environment visual quality, floating panel interaction quality (box menu), information content availability, variety of in-app features. Measure the respondents' assessment of the Kayutangan Metaverse using the variables in this study. The ten variables are arranged in a bipolar semantic differential scale with 5 linear scales, each with a value. An inferior linear scale has a value of 1, a poor linear scale has a value of 2, an average linear scale has a value of 3, a good linear scale has a value of 4, and the last is an excellent linear scale has a value of 5 (Ernawati & Moore, 2014).

The digitization process allows for precise digital duplicates of cultural heritage structures. Occasionally, historical edifices necessitate replicating specific damaged or missing components. Digital information facilitates more effective preparation and execution of maintenance efforts. Various parties, including architects, conservators, scientists, and other interested parties, can readily exchange and consult this digital information. The sustainability of preserving cultural heritage structures can be enhanced by possessing comprehensive digital records. Digital data can also contribute to disaster preparedness, such as safeguarding against earthquakes, floods, or fires. The advantages of the digitalization approach, which can yield numerous benefits, underscore the importance of its widespread adoption for conserving cultural heritage buildings.

3. Result

Digitization is capturing physical items of the Kayutangan area (photographs, architectural blueprints, drawings, or artifacts) into digital or computerized formats. Digitization is usually for cultural heritage, especially for preserving older historical buildings or architectural landmarks. The following are several methods of digitizing cultural heritage buildings, depending on the size of the building, its condition, and available resources. This study will examine 6 digitization methods by assessing the advantages and disadvantages of digitization, namely Kayutangan 3D modeling, Decision Support System Models, HBIM, Photo and Modeling 360, Augmented Reality, and finally, the Metaverse. The success rate of this type of technology digitization for users is highly dependent on the leveling of spatial understanding. The leveling of spatial understanding refers to acquiring and developing knowledge and skills related to spatial awareness and perception. It involves understanding and navigating physical spaces, visualizing objects and their relationships in three-dimensional (3D) environments, and mentally manipulating and reasoning about spatial information.

3.1 Visual-Spatial Data Mining

Visual-spatial data mining is an approach to data exploration and analysis focusing on data with a visual or spatial component. Visual data mining of building appearance data using photo mapping with drones or UAV (Unmanned Aerial Vehicle) and 3D laser scanner (Leica RTC E60), then visual-spatial data of street views of buildings were obtained using 360° photos and 360° videos.

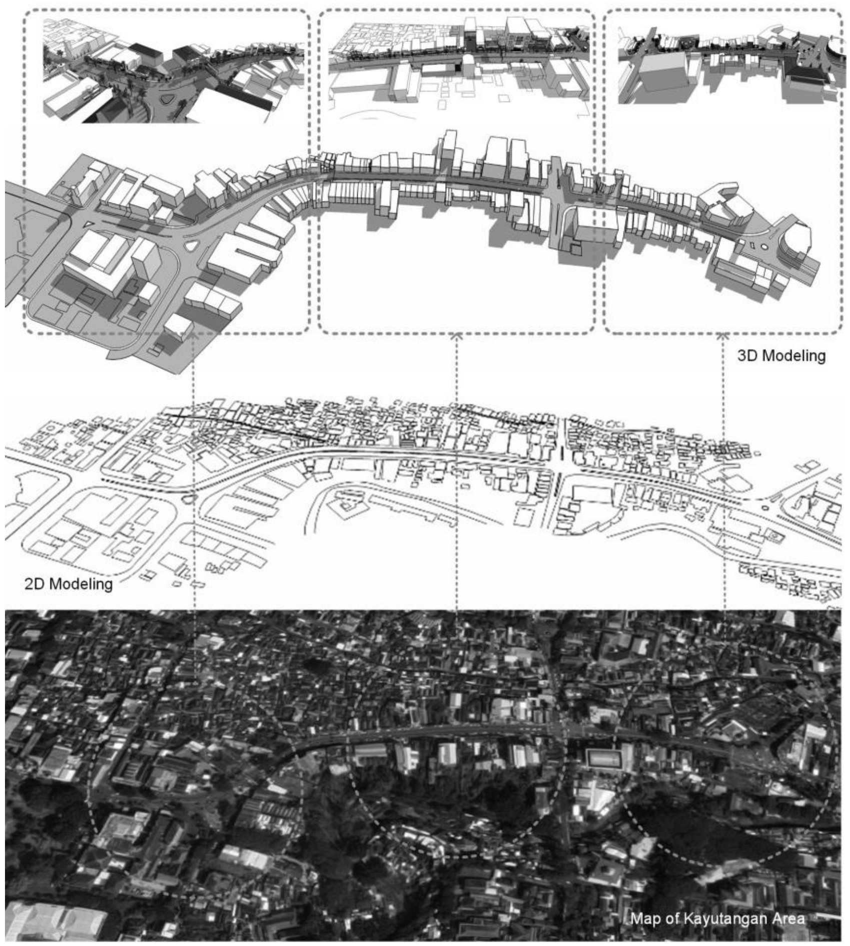

Figure 3. Visual-spatial data mining of Kayutangan Heritage

The visual data on the appearance of the building and the visual-spatial data on the Kayutangan building's streetscape are translated into a visual illustration in the form of 2D modeling, then processed into 3D to make it more accurate and then detailed according to the existing condition of the building and the Kayutangan streetscape area (see Figure 3.).

3.2 3D Modeling, Visualization, and Simulation

Two industry-leading programs, Autodesk Revit and ArchiCAD, are used to reconstruct digital 3D models of historic structures. Autodesk Revit software is used for the crucial modeling phase and flattening 3D point cloud data for each historic building. In contrast, the ArchiCAD software is designed for the detailed and thorough 3D digital modeling of historic buildings, which involves the modeling stage of additional 3D point clouds for each historic building. An example of the process stages can be seen in Figure 4.

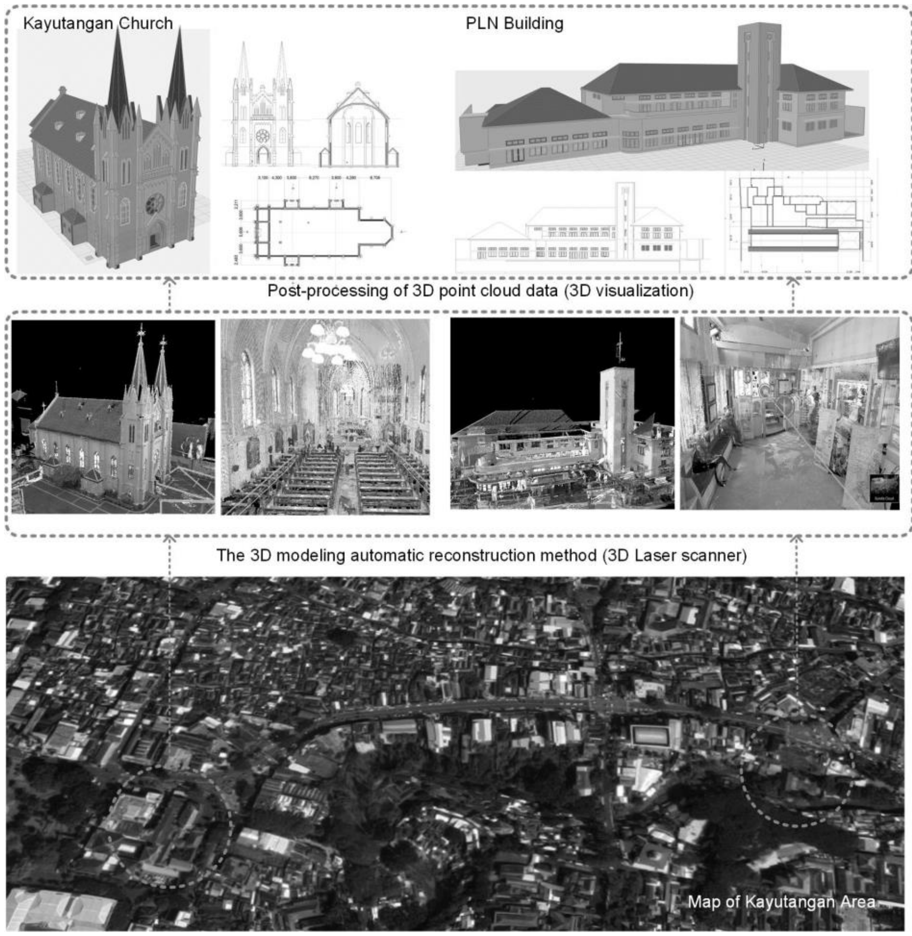

Figure 4. The development of 3D Modeling, Visualization, and Simulation of Kayutangan Heritage

The primary modeling stage and leveling 3D point cloud data for each historical building are the following steps in the Autodesk Revit software process. The technical procedures followed include the following for Autodesk Revit's 3D point cloud processing: Importing point clouds (RCP/RCS), leveling, tracing buildings, tracing details (door, glass, and facade tracing), and exporting simple tracing results in ifc form (.ifc).

The subsequent step is to model each historical building's 3D point cloud data in ArchiCAD. The technical steps involved in the process are as follows: opening the IFC file from Revit, tidying up the layers (unlock, visibility), creating columns and plates, creating the roof (roof, shell, and custom type), creating assets (archicad - immersion sketch), inserting assets (glass, doors, facades, details), publishing settings (pages, scale, notation), and publishing (BIMx, project paper).

3.3 Application System Development

Newer digitalization methods are developed based on data sources from digitalization methods, such as virtual reality, augmented reality, and Metaverse (see Figure 5&6.). Virtual reality offers a simulated experience that allows users to interact and explore urban environments in a highly immersive and interactive way. Virtual reality models provide a highly realistic and immersive urban environment experience. The immersive nature of VR enhances spatial perception, allowing users to explore the scale, proportions, and spatial relationships of urban elements. Multiple users can access the VR environment simultaneously, enabling interactive discussions, design reviews, and feedback sessions. Users can also experience the spatial quality of streetscapes, public spaces, and buildings, assessing lighting, pedestrian comfort, and accessibility. VR facilities can identify potential problems and support the design of user-friendly and inclusive urban environments. Virtual reality models can simulate future scenarios and their potential impact on urban spaces.

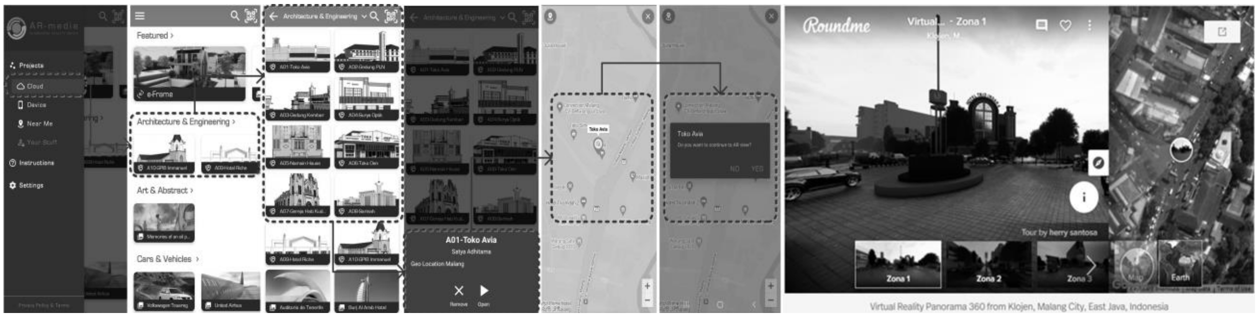

Figure 5. The development of Augmented Reality and VR Panorama 360 application

Augmented reality layers digital information into real-world environments, allowing users to interact and enhance their perception of urban spaces. Augmented reality provides users a real-time overlay of information about the physical environment. Users can view relevant data, such as points of interest, historical information, or real-time transportation updates, directly on their mobile devices or AR glasses. AR improves spatial understanding by providing contextual information that improves the interpretation and navigation of urban spaces. Augmented reality can improve navigation and wayfinding in urban environments. By overlaying historical images, videos, or 3D reconstructions onto existing structures or locations, users can experience the evolution of the urban environment over time. AR improves spatial understanding by connecting the present with the past and highlighting the cultural significance of different areas within a city. Augmented reality can facilitate public participation in urban planning and design processes. AR empowers communities to actively participate in urban planning decision-making actively, fostering a sense of ownership and enabling more inclusive and transparent decision-making processes.

The latest development is metaverse technology. The concept of the Metaverse, a virtual shared space that combines physical and virtual reality, can provide significant benefits to urban spatial understanding. Users can explore this virtual city space, feeling the presence and experience. The Metaverse allows individuals to understand better the urban environment, including layout, architecture, and design elements, even while physically distant from the actual location. Metaverse enables more inclusive, participatory, and efficient decision-making, encouraging creativity and innovation in urban design and planning. Metaverse provides a platform for simulating and testing urban interventions. Metaverse allows experimentation with design options, traffic patterns, zoning regulations, and other variables. Through simulation and testing, stakeholders can make more informed decisions, optimize urban design, and identify potential problems before implementation.

Figure 6. The development of Metaverse Kayutangan Heritage

The Metaverse has the potential to integrate augmented reality (AR) technology, enabling users to superimpose digital information onto the real-world urban environment. Metaverse offers a transformative platform for urban spatial understanding by combining virtual and physical reality. The process of digitizing cultural heritage buildings, a novel approach, is continually evolving and under ongoing assessment to understand its pros and cons comprehensively.

Testing of the development of Kayutangan metaverse technology through respondent testing with a figure of 81.0% stating that Kayutangan metaverse technology is "good." This study uses mean analysis to identify respondents' assessment of the Kayutangan Metaverse. The average analysis results will show the assessment's classification with the applicable calculation formula. Mean analysis in this study using the SPSS application. Calculate the average yield using the formula for determining respondents' attainment level in the Kayutangan Metaverse. Respondent achievement level: mean X 100 / maximum score.

Table 2. The classification level of achievement respondents

No	Achievement Percentage	Criteria
1.	85%-100%	Excellent
2.	66%-84%	Good
3.	51%-65%	Average
4.	36%-50%	Poor
5.	0%-35%	Very Poor

Calculation results of the Kayutangan Metaverse analysis based on a community questionnaire stated that the Kayutangan Metaverse was "good" with the following calculations:

Mean score= 40.5

Respondent achievement level: mean X 100 / maximum score

= 40.5 X 100 / 5 = 81.0%

The calculation of the respondent's level of achievement against the Metaverse Kayutangan stated the result was 81.0% to the classification table of the respondent's level of achievement can be categorized into the excellent category after carrying out the mean analysis, followed by frequency analysis (see Table 2.). Frequency analysis is a statistical technique used in calculations using the SPSS (Statistical Package for the Social Sciences) application. SPSS summarizes and analyzes the distribution of categorical or discrete variables in a data set. Frequency analysis in SPSS is a fundamental tool for summarizing and exploring the distribution of categorical variables in a dataset. It assists researchers in data validation, descriptive analysis, cross-tabulations, and assessing associations between variables using chi-square tests.

Table 3. Frequency analysis

Variable	Sub Variable	Category	Frequency	Percentage
General assessment	System performance	Good	21	65.6
		Excellent	11	34.4
	System understanding	Average	4	12.5
		Good	17	53.1
		Excellent	11	34.4
	System usability	Average	9	28.1
		Good	15	46.9
		Excellent	8	25.0
Operation of the system	System response speed	Average	6	18.8
		Good	14	43.8
		Excellent	12	37.5
Quality of visualization	Text quality	Poor	2	6.3
		Average	6	18.8
		Good	18	56.3
		Excellent	6	18.8
	Human and object visualization quality	Poor	2	6.3
		Average	7	21.9
		Good	14	43.8
		Excellent	9	28.1
	Virtual environment quality	Poor	2	6.3
		Average	5	15.6
		Good	15	46.9
		Excellent	10	31.3
Quality of user interaction	Floating panel interaction quality	Poor	1	3.1
		Average	7	21.9
		Good	16	50.0
		Excellent	8	25.0
	Availability of information content	Poor	2	6.3
		Average	6	18.8
		Good	7	21.9
		Excellent	7	21.9
	Diversity of application features	Average	8	25.0
		Good	14	43.8
		Excellent	10	31.3

Identification of categories in the Kayutangan metaverse test frequency table, which does not have flawed criteria and averages only on system performance sub variables with a frequency of 21 respondents in the excellent category and a percentage value of 65.6, then the frequency of 11 respondents in the good category excellent category and a percentage value of 34 .4, thus the respondents have a good assessment of the performance of the Kayutangan metaverse system (see Table 3.).

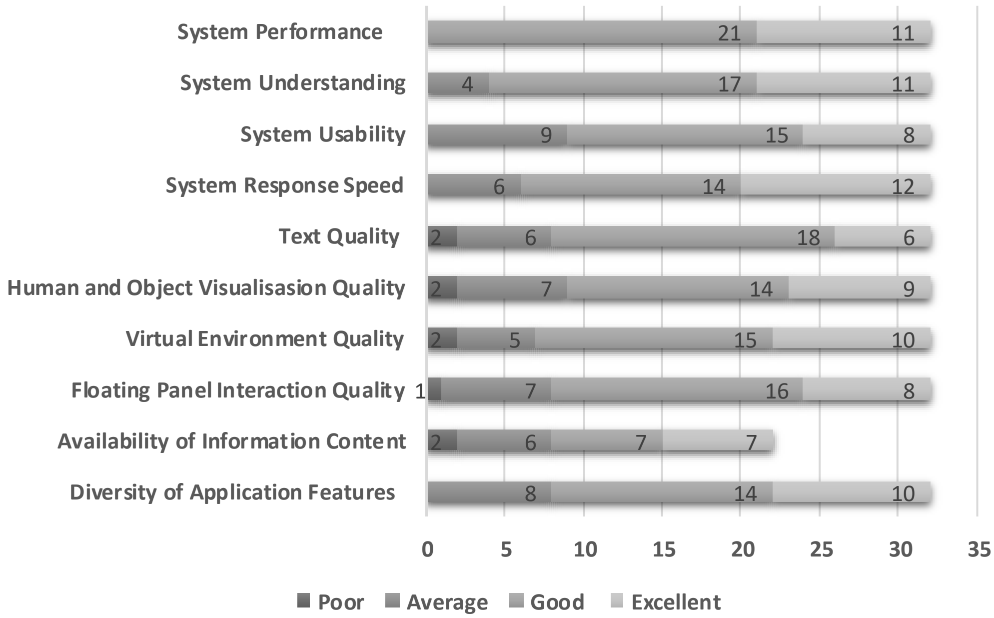

Figure 7. Frequency value chart

The graph of frequency values shows that respondents rated the Kayutangan metaverse as having good system performance, system understanding, text quality, and floating panel interaction quality and had to evaluate the quality of human and object visualization, virtual environment quality, and availability of human information content (see Figure 7.).

4. Discussions

The digitalization of historic buildings for urban heritage governance offers significant benefits and has the potential to transform how we understand, preserve, and engage with our cultural heritage. In the last five to ten years and concur with the statement of Noor Azizu et al. (2011) and De Fino et al. (2022), the research trend towards intensifying urban heritage management efforts through digitalization for various dissemination, assessment, and management activities of historic buildings in order to maintain the authenticity and historical character while maintaining the sustainability of building functions has increased along with the development of advanced technologies. Several examples of research precedents that illustrate the increasing use of digitalization technology in historical buildings sequentially, starting from the use of virtual devices, 3D modeling, and photogrammetry to 3D point clouds, are Gonizzi Barsanti et al. (2015), Koeva (2016), Lo Brutto et al. (2018), Thwaites et al. (2019), Herban et al. (2022).

At the Visual-Spatial data mining stage, recording historical buildings also uses 3D laser scanning, which is in line with Murphy & King (2016), Thwaites et al. (2019), and Herban et al. (2022) that the use of the latest technology developments in recording physical data is essential to maintain modeling accuracy and increase the efficiency of physical data recording activities for historical building objects and data post-processing. Advanced technologies such as 3D scanning virtual and augmented reality can capture and document historic buildings' intricate details, create immersive experiences, and enhance decision-making processes. One of the critical benefits of digitalization is the accurate documentation and preservation of historic buildings. Creating detailed 3D models ensures that architectural features, materials, and craftsmanship are true to life (Chiabrando et al., 2017; Lo Brutto et al., 2017; Gagliolo et al., 2017; D'Aprile & Piscitelli, 2019; Teruggi & Fassi, 2022). These digital records serve as a valuable resource for restoration, research, and education, ensuring that the knowledge and beauty of these structures are developed for future generations (Montusiewicz et al., 2022). Reconstruction of 3D point cloud data in the 3D building modeling stage optimizes the use of the Autodesk Revit and Graphisoft ArchiCAD applications to produce informative 3D structural modeling of historic buildings and stimulates the general public's interest in buildings more deeply (Tytarenko et al., 2023). Panou et al. (2018) and Liu et al. (2023) strengthen those digital replicas and virtual reconstructions offer new public engagement and interpretation opportunities.

Application development using Augmented Reality technology in this study strengthens the statement of Elbshbeshi et al. (2023) regarding the creation of a 3D virtual tour that can influence and increase user perceptions of attachment and interest in cultural heritage buildings through real-time overlay of information on the building's physical environment. Moreover, developing a public 3D virtual tour application can increase the openness of shared digital heritage sites, which encourages cultural exchange and appreciation of the diversity of cultural heritage in the world

(Susanna et al., 2021). Through virtual and augmented reality technologies, individuals can virtually explore and interact with historic buildings, fostering a deeper appreciation for their cultural significance. This immersive experience enhances the understanding and emotional connection to urban heritage, creating a sense of place and history within the urban fabric. Furthermore, the latest development in the digitalization of historic buildings is Metaverse technology. In line with Damar (2021), Metaverse is changing how people see everything connected to the Internet, which can build a virtual shared space combining physical and virtual reality, providing a better understanding of buildings and the city environment. The Metaverse has the potential to integrate augmented reality (AR) technology, enabling users to superimpose digital information onto the real-world urban environment.

Eventually, the digitalization of historic buildings also benefits urban heritage governance by supporting better decision-making. Urban planners and policymakers can utilize digital models to assess the impact of proposed developments on the visual integrity and historical context of these structures. Virtual simulations enable the evaluation of different scenarios, identification of potential conflicts, and informed choices that balance heritage conservation with urban development goals. This digital toolset supports sustainable urban planning that recognizes the importance of preserving our cultural heritage while creating livable and vibrant cities.

Ultimately, digitalization facilitates research, education, and interpretation of historic buildings. Scholars, students, and the wider public can explore these digital replicas, studying architectural styles, historical significance, and cultural influences (Allam et al., 2022). Online platforms, virtual exhibitions, and educational resources can disseminate knowledge to diverse audiences, transcending physical limitations and promoting a broader appreciation for urban heritage. While the benefits of digitalization are significant, there are also some shortcomings and considerations to address. Privacy concerns, ethical considerations, and careful data management systems ensure digital replicas' accuracy, authenticity, and integrity. Collaboration between heritage professionals, technologists, and stakeholders is essential to ensure responsible digital preservation practices. Another challenge is the digital divide and equitable access to these digital resources. It is essential to ensure that the benefits of digitalization reach all communities, bridging the gap between those who have access to technology and those who do not. Make digital heritage resources inclusive and accessible to diverse populations.

This study summarized the strengths and weaknesses of digitization, including 3D modeling, Decision Support System (DSS) modeling, Historic Building Information Modeling (HBIM), 360° photography and modeling, Augmented Reality, and the Metaverse (see Table 4.).

Table 4. Digital comparison

No.	Digitization Method	Strengths	Weaknesses
1.	3D-Modeling Kayutangan	Kayutangan 3D modeling allows visualization of spatial landscapes so users can see the area at a glance.	There is no way to monitor how accurate the model is because there is no validation against the real world.
2.	Decision Support System (DSS) Model	DSS is applicable for helping decision-makers understand how various factors can play a role when making decisions, providing a comprehensive picture.	Decision Support System models require a high initial investment in software and the time required to enter data into the software.
3.	HBIM	HBIM (High-Level BIM) is a 3D modeling system incorporating more product orientation than spatial information.	HBIM systems may not be able to accurately represent battlefield topography because they do not consider local soil conditions, geography, or other external factors.
4.	Photo and Modeling 360°	Digital models that generally lack detail can be created quickly by taking photos and videos in spherical format.	While this technique efficiently captures digital models that lack detail, it provides a different level of detail than 3D models.
5.	Augmented Reality	Augmented Reality (AR) is a promising technology for the Kayutangan area because it allows users to interact with 3D models of the area in a virtual reality environment.	AR accuracy is highly dependent on the accuracy of the data and underlying mapping algorithms.
6.	Metaverse	Metaverse enables surveyors and planners to interact and explore data at scale while providing engaging user experiences.	One of the main areas of improvement for the Metaverse is that it is difficult to ensure accuracy because there is no way to validate the data.

A comparison between the six digitization methods examines the advantages and disadvantages of each method so that it can be used as a further study considering the comparisons made. All digital technology methods can also help create access and awareness of a city's heritage.

Test results of Kayutangan Metaverse technology trials show that the Kayutangan Metaverse is an excellent effort to explore the digitization of historic buildings for urban heritage management in Kayutangan. Several things still need to be evaluated in the Kayutangan metaverse system, namely, the quality of human and object visualization, the quality of the virtual environment, and the availability of human information content and maintaining or even improving system performance, system understanding, text quality, and floating panel interaction quality. Overall, the development of the Kayutangan Metaverse prototype opens up technological digitalization opportunities in the development of new management of historic buildings and areas that offer a transformative platform for urban spatial understanding by combining virtual and physical reality to enable much more—inclusive, participatory, and efficient decision making, encouraging creativity and innovation in urban design and planning.

5. Conclusion

In conclusion, digitalizing historic buildings for urban heritage governance represents a transformative approach that enhances our understanding, preservation, and engagement with our cultural heritage. By harnessing advanced technologies, we can accurately document and preserve historic buildings, create immersive experiences, support decision-making processes, and foster research and education. However, addressing privacy concerns, ethical considerations, and equitable access is crucial to ensure responsible and inclusive digital heritage practices. By embracing the potential of digitalization, we can protect, celebrate, and share the stories embedded within our historic urban landscapes, promoting sustainable, liveable, and culturally rich cities for future generations.

Research on digitizing the management of Kayutangan City's cultural heritage is fundamental to preserving and managing this valuable cultural heritage. This research aims to produce accurate and comprehensive digital data about Kayutangan, including historic buildings, structures, and the surrounding environment. This research improves efforts to preserve and manage Kayutangan. Exploration of the digitalization of historic buildings for urban heritage management continues to be developed to increase the representation of human accessibility and interaction with digital content. In the future, the digital data obtained can be used to plan the maintenance and restoration of historic buildings, ensure environmental safety, and promote cultural tourism. Digital tools support opens public access to heritage information online, which can encourage increased participation in heritage conservation and support the spread of local cultural experiences. Virtual tours and other media outlets can provide a more immersive way for people to engage with their city's past and an interactive way to help preserve and foster a deep sense of place. In addition, with digitalization, information about Kayutangan can be more easily accessed and shared with the broader community, educators, and researchers for further educational and research purposes.

For future work, it is essential to concentrate on improving the representative quality of avatars, enhancing immersive virtual environments, and improving interaction patterns and information availability by focusing on human interactive responses to virtual environments.

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