Indonesian Journal of Computer Science
ISSN 2549-7286 (*online*)
Jln. Khatib Sulaiman Dalam No. 1, Padang, Indonesia
Website: ijcs.stmikindonesia.ac.id | E-mail: ijcs@stmikindonesia.ac.id

Developing Digital Interactive Exploration of Historical Places with Blending BIM and Virtual Reality

Ketut Tomy Suhari[1], Hery Purwanto[2], Ratri Andinisari[3]
ksuhari@lecturer.itn.ac.id, hery.purwanto@lecturer.itn.ac.id, aratri@lecturer.itn.ac.id
[1,2]Department of Geodesy Engineering, Faculty of Civil Engineering and Planning, Institut Teknologi Nasional Malang
[3]Department of Civil Engineering, Faculty of Civil Engineering and Planning, Institut Teknologi Nasional Malang

Article Information

Submitted : 25 Jan 2024
Reviewed: 29 Jan 2024
Accepted : 19 Feb 2024

Keywords

BIM, VR, Historical Places, Digital Exploration, Immersive Experience

Abstract

The advancement of technology has opened new possibilities for exploring and experiencing historical places. This research aims to develop a digital interactive exploration platform that blends BIM and VR to provide an immersive and informative experience of historical sites. The study focuses on Candi Kidal, located in Kecamatan Tumpang, Kabupaten Malang, as the primary study area. The proposed method involves the integration of BIM and VR technologies to create a detailed and interactive virtual representation of Candi Kidal. The BIM models are the foundation for capturing and integrating various data sources. These models are then transformed into a VR environment, allowing users to explore the site virtually, interact with objects, and access relevant historical information. Data collection methods include site surveys, and historical research in the field. The BIM models are developed using software tools such as Autodesk Revit, while the VR environment is created using platforms like Unity3D. The development of the digital interactive exploration platform involves programming and scripting languages such as C#. The results demonstrate the effectiveness of developed platform in providing an immersive and informative experience for Candi Kidal. Users can navigate the virtual environment, view detailed architectural elements, and access historical information through interactive interfaces. The significance of this research lies in its potential to enhance the preservation, promotion, and accessibility of historical places. By blending BIM and VR technologies, the digital interactive exploration platform offers a unique and engaging experience that can attract a wider audience and foster a deeper understanding of cultural heritage..

A. Introduction

The digital representation and exploration of historical places have gained significant attention in recent years, offering unique opportunities to engage with cultural heritage and promote its preservation [1]. One promising approach is the blending of Building Information Modeling (BIM) and Virtual Reality (VR) technologies, which enables the creation of immersive and interactive experiences for users [2]. BIM is a collaborative approach that utilizes 3D models and integrates information from various disciplines, allowing for the comprehensive representation of buildings and their components. It is a digital repository that captures geometric, semantic, and relational data, providing a holistic view of the building throughout its lifecycle [3]. By incorporating BIM into developing a digital interactive exploration platform for historical places, the platform can leverage the rich data embedded within the BIM model to enhance the virtual experience [4].

Integrating VR technology further enriches the exploration process by creating a highly immersive and interactive environment [5]. VR enables users to experience historical places in a visually compelling and realistic manner, transcending the limitations of traditional 2D representations [6]. By putting users at the center of the virtual environment, VR allows them to navigate and interact with the historical site virtually, creating a sense of presence and a deeper connection with the past [7]. Moreover, VR can simulate different periods, architectural styles, and scenarios, providing a dynamic and flexible exploration experience [8]. Blending BIM and VR technologies offer a synergistic approach to the digital representation and exploration of historical places. It combines the detailed information captured in the BIM model with the immersive capabilities of VR, enabling users to engage with historical sites in a multidimensional and interactive manner [4]. This approach can potentially revolutionise how we perceive, study, and preserve cultural heritage by providing a compelling and accessible medium for exploring historical places. The significance of this research lies in the potential to enhance the understanding and appreciation of historical sites, such as the exploration of ancient architecture, cultural significance, and historical narratives [9]. By leveraging BIM, which integrates multidisciplinary information about buildings, and VR, which provides a realistic and immersive environment, users can engage with historical places in a virtual setting [10]. This approach allows for detailed exploration, interactive experiences, and access to relevant historical information.

Figure 1 is the study area in Candi Kidal, located in Kecamatan Tumpang, Kabupaten Malang, offers a unique opportunity to develop a digital interactive exploration platform that blends BIM and VR technologies. Candi Kidal is an ancient historical site that holds cultural and historical significance. The site features intricate architectural details and rich historical narratives that attract local and international visitors [11], [12]. By focusing on Candi Kidal as the study area, researchers can explore the application of BIM and VR technologies to enhance the virtual experience of this historical site. They can leverage the available data, such as architectural plans, historical documentation, and cultural context, to develop a comprehensive BIM model that accurately represents the site. This model can then be integrated with VR technology to create an immersive and interactive virtual environment.

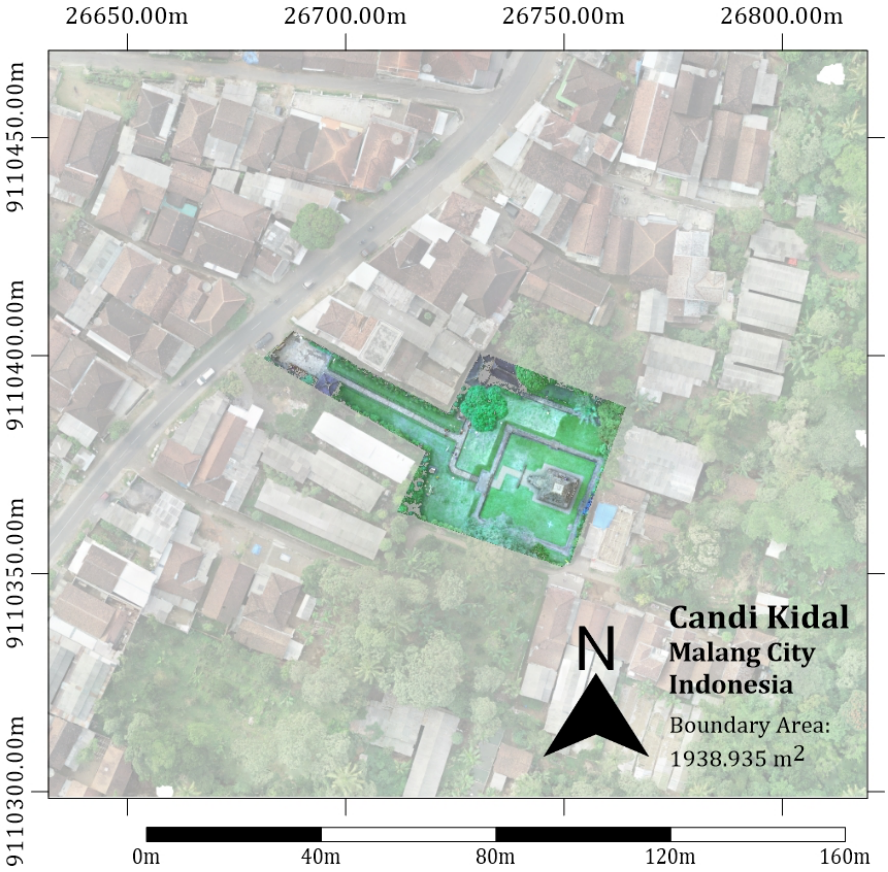

Figure 1. Study area of interest in Candi Kidal

Candi Kidal provides a diverse range of architectural elements, sculptures, and historical artefacts that can be digitally reconstructed and experienced in VR. Researchers can capture the site's unique characteristics, such as the intricate stone carvings and spatial layout, and recreate them in the virtual environment. This allows users to explore and interact with the site as if physically present, providing a deeper understanding and appreciation of its historical and cultural significance. Furthermore, the study area in Candi Kidal is a representative example that can be applied to other historical places. This research's methodologies, algorithms, and findings can be generalized and implemented in various locations, enabling the digital interactive exploration of historical sites anywhere. This opens up opportunities for cultural heritage preservation, promotion, and educational utilization worldwide.

The objectives of this study are twofold. First, to develop a methodology for blending BIM and VR technologies to create a digital interactive exploration platform. Second, to assess the effectiveness and user experience of the developed platform in the context of a specific historical place. To achieve these objectives, this research paper will present the proposed method/algorithm, the research methodology, the development process, and the evaluation of the digital interactive exploration platform. The results and discussion section will present the study's findings, including the technical implementation, user feedback, and the platform's impact on the exploration and understanding of historical places.

Finally, the paper will summarise the key findings, their implications, and suggestions for future research or improvements to the proposed method.

This research aims to contribute to digital heritage preservation and provide insights into the potential of blending BIM and VR technologies for the interactive exploration of historical places. By enabling users to virtually experience and engage with cultural heritage, this approach has the potential to promote awareness, education, and appreciation of our rich historical past.

B. The Proposed Method

The proposed method for developing the digital interactive exploration of historical places by blending BIM and virtual reality (VR) is based on systematically integrating BIM data and VR technology to create an immersive and interactive virtual experience. The rationale behind this approach lies in the complementary strengths of BIM and VR, which can enhance historical sites' visualization, contextualization, and interactivity.

Firstly, the proposed method involves the creation of a comprehensive BIM model of the historical place. BIM provides a collaborative platform integrating data from various disciplines, including architectural, structural, and historical information. Various data sources, such as point cloud data from field surveys (e.g., geodetic surveying, LiDAR, and UAV), are required to create a BIM [13]–[16]. These data are processed using either the As-built or shop drawing methods [17]. Ensuring that the BIM model is in the standardized IFC format is important. In addition to the geometric data, semantic data obtained from interviews is integrated into the BIM model. To ensure compatibility with the VR platform, the integrated data is exported to OBJ and XML formats, widely supported by Unity3D, a popular game engine. This data integration allows for the accurate representation of the physical and contextual aspects of the historical site. The BIM model is the foundation for virtual reconstruction and visualization in VR.

The development of the VR platform requires meticulous attention to detail and specialized skills. To enhance user interactivity, various menus are incorporated into the platform through the development of C# scripts. These scripts enable functionalities such as user movement, pointer triggers, and level changes. VR offers the ability to simulate realistic and immersive experiences, enabling users to explore and interact with the historical place in a virtual setting. Integrating BIM and VR has a significant impact as it allows users to interact with virtual objects, providing a more immersive and engaging experience.

When users interact with specific objects in the historical site, the corresponding data must be retrieved or queried. A database is utilized to store the BIM data to facilitate this process. This database enables the creation, updating, editing, and deletion of BIM data as needed, ensuring efficient access to the required information during the interactive exploration of the site. By integrating BIM data into VR, users can visualize the site's architectural elements, spatial layout, and historical context more engagingly and interactively.

The proposed method also considers the user experience and interaction design principles to ensure a seamless and intuitive exploration process. User-friendly interfaces, intuitive navigation controls, and interactive elements enhance the user's engagement and understanding of the historical place. Additionally, the

proposed method may include advanced features such as multimedia integration, historical narratives, and interactive storytelling to enrich the virtual experience. This can involve audio guides, historical documentation, and visual representations that provide additional context and information about the site. A more detailed explanation can see Figure 2.

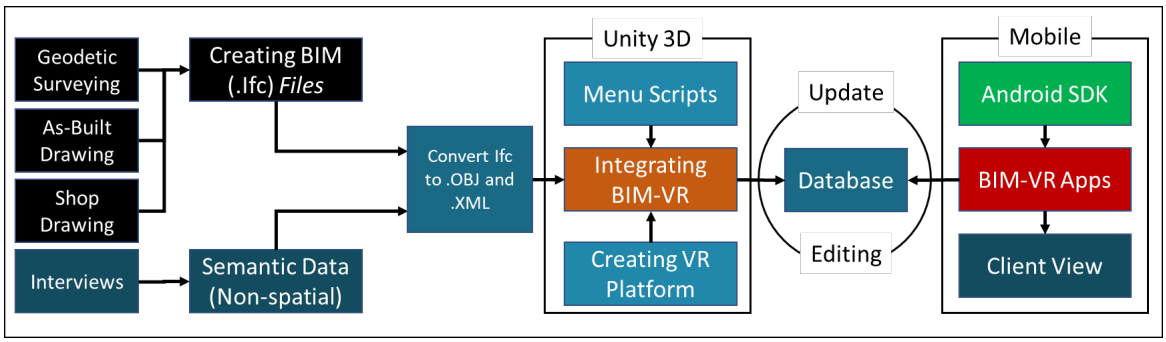

Figure 2. The proposed methods

The rationale behind the proposed approach is to leverage the strengths of BIM and VR to create a digital interactive exploration platform that enhances the understanding, appreciation, and accessibility of historical places. By blending these technologies, users can virtually experience the historical site with a high level of detail, interactivity, and contextual information. The proposed method aims to bridge the gap between traditional historical preservation and modern technology, offering new opportunities for cultural heritage preservation, education, and tourism promotion.

During the application speed testing, the rendering time for each menu and the calling or interaction between objects were taken into account. The average speed test value can be calculated using equation (1).

$$\bar{v}_t = \frac{\sum v_t}{n} \tag{1}$$

In equation (1), $\bar{v}_t$ represents the average speed. $\sum v_t$_t is the sum of speed test scenarios from each individual test in the application menu, while n represents the total number of tests conducted.

C. Methods

1. Authoring semantic information in BIM models

Authoring semantic information in BIM models involves assigning meaningful and structured data to the elements and components within the model [18]. This semantic information goes beyond geometric representation and includes attributes such as functional characteristics, material properties, and construction specifications [3]. The process of authoring semantic information typically begins by identifying the relevant data requirements for the project or facility [19]. This involves understanding the specific information that needs to be associated with each element in the BIM model to support various project stages and use cases.

Once the data requirements are established, the semantic information can be added to the BIM model using industry-standard formats such as Industry Foundation Classes (IFC) or proprietary data schemas. This involves assigning appropriate attributes, properties, and classifications to the model elements based on predefined standards or project-specific requirements. The authoring of semantic information may involve manual input by professionals with domain knowledge and expertise. Alternatively, automated processes such as data extraction from external sources or rule-based algorithms can be employed to populate the semantic data in the BIM model [20].

By incorporating semantic information in BIM models, stakeholders can benefit from enhanced data interoperability, improved decision-making processes, and better coordination among disciplines. The semantic data enables advanced functionalities such as quantity take-offs, clash detection, energy analysis, facility management, and asset tracking throughout the lifecycle of the project or facility. Authoring semantic information in BIM models is a crucial step in harnessing the full potential of BIM technology to facilitate data-driven workflows and optimize the design, construction, and operation of built environments.

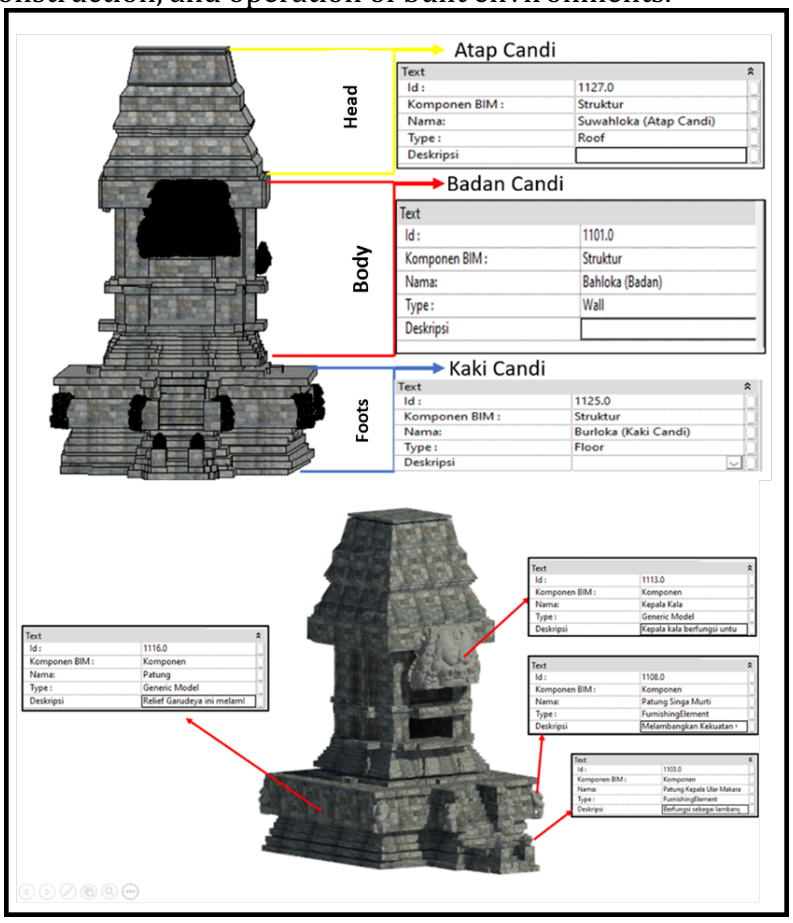

Figure 3. Authoring Semantic Information

2. Integrating BIM and VR process

The development of the digital interactive exploration platform involves several stages. First, the 3D model of the historical site, in this case, Candi Kidal, is created using BIM software. The BIM model includes the site's geometric, attribute,

and relational data. This data is then used to create the virtual reality environment. The BIM model is imported into the virtual reality software and converted into a format compatible with the virtual reality environment. Next, the interactive features are added to the virtual reality environment. These features include navigating the site, viewing details of specific elements, and accessing relevant historical information. The user interface is also designed to be intuitive and easy to use. Finally, the platform is tested and refined to ensure a seamless and immersive user experience. User feedback is collected and used to make improvements to the platform. The result is a digital interactive exploration platform that blends BIM and virtual reality technologies to create an immersive and informative experience of historical places.

We are integrating BIM and virtual reality to transform the static BIM model into an interactive and immersive digital exploration of Candi Kidal, enabling users to experience the historical site dynamically and engagingly virtually.

3. Technical details and tools used

The development of the digital interactive exploration platform involved using several technical tools and software. The BIM model of Candi Kidal was developed using Autodesk Revit, a BIM software that allows for creation of accurate 3D models of buildings and their components. The BIM model was then exported to Unity, a real-time 3D development platform, where the virtual reality environment was created. To ensure seamless integration between the BIM model and the virtual reality environment, the Unity platform was augmented with the BIM 360 platform, which provides cloud-based access to the BIM model data. This allowed for the incorporation of real-time changes to the BIM model during the virtual reality exploration.

The virtual reality environment was created using the HTC Vive headset and controllers, which provided an immersive experience for the user. The interaction with the environment was achieved using Unity's scripting system, which allowed for creation of interactive elements within the virtual reality environment. To enhance the user experience, the platform was developed with a user-friendly interface and interactive elements, such as hotspots and tooltips, that provided information about the historical and architectural significance of the various elements of Candi Kidal. The platform was also developed with a narrative structure that guided the user through the exploration of the historical site while providing relevant information about the history and architecture of the site.

D. Results and Discussion

1. Interactive Apps

The results obtained from developing the digital interactive exploration platform using the blending of BIM and virtual reality were highly promising. The platform successfully provided users with an immersive and interactive experience of exploring Candi Kidal, allowing them to interact with the historical site in a virtual environment.

In Figure 4, the visualization of Candi Kidal is divided into three parts: the base of the temple (Bhurloka), the body of the temple (Bhuvarloka), and the roof of the

temple (Svarloka). The structure menu displays the structural components of Candi Kidal using the hide and show mode.

The Candi roof is depicted as a three-tiered stacked box that tapers toward the top. The AR visualization provides information about the roof component of the temple, including its Name: Roof, Id: 1001, BIM Component: Structure, and Type: Roof. The body of the Candi is represented in the VR visualization, displaying information such as its Name: Body, Id: 1002, BIM Component: Structure, and Type: Walls. The base of Candi Kidal has a square shape with stairs at the front leading to the upper part of the Candi. The visualization details the base component, including its Name: Base, Id: 1003, BIM Component: Structure, and Type: Floor.

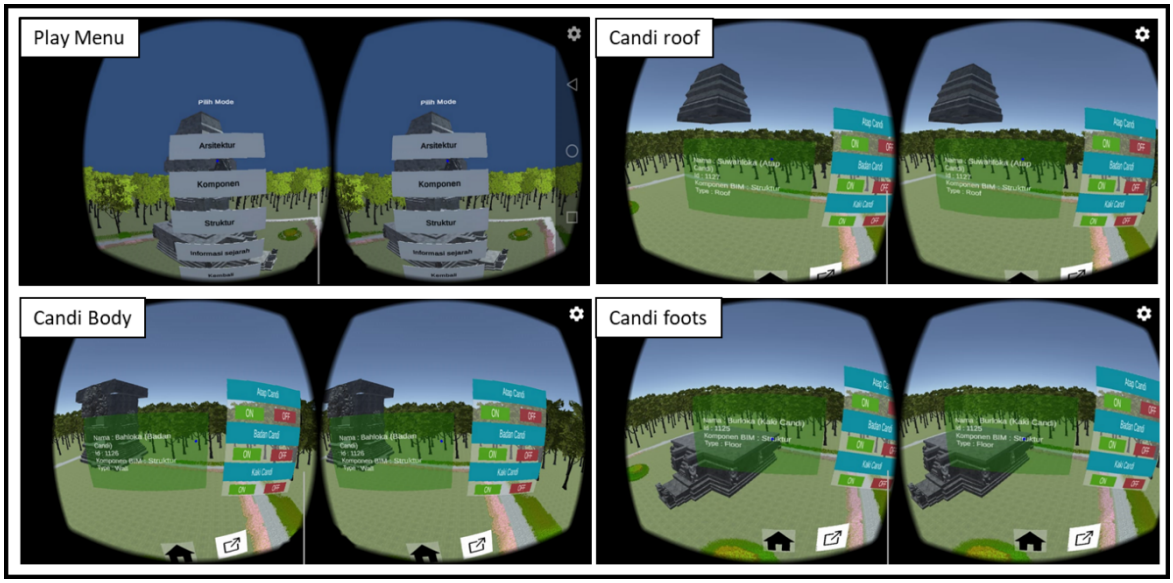

Figure 4. Interface of BIM-VR

The visualizations and accompanying information allow users to explore and understand the different architectural elements of Candi Kidal in a virtual environment. Users can selectively view and analyze each component by utilizing the hide and show feature in the structure menu, enhancing their knowledge and appreciation of the temple's design and construction. The BIM integration process effectively created a detailed and accurate representation of Candi Kidal. Users could navigate through the virtual environment and observe the architectural components of the historical site with precision and clarity. The integration of BIM data allowed for real-time updates and changes to be reflected in the virtual reality environment, ensuring the accuracy and relevance of the information presented to the users. The virtual reality aspect of the platform enhanced the overall experience by creating a sense of presence and immersion. Users could walk around the virtual environment, examine the intricate details of the architecture, and experience the ambience of the historical site (Fig 5). The interactive elements, such as hotspots and tooltips, provided additional information and context, enriching the exploration process.

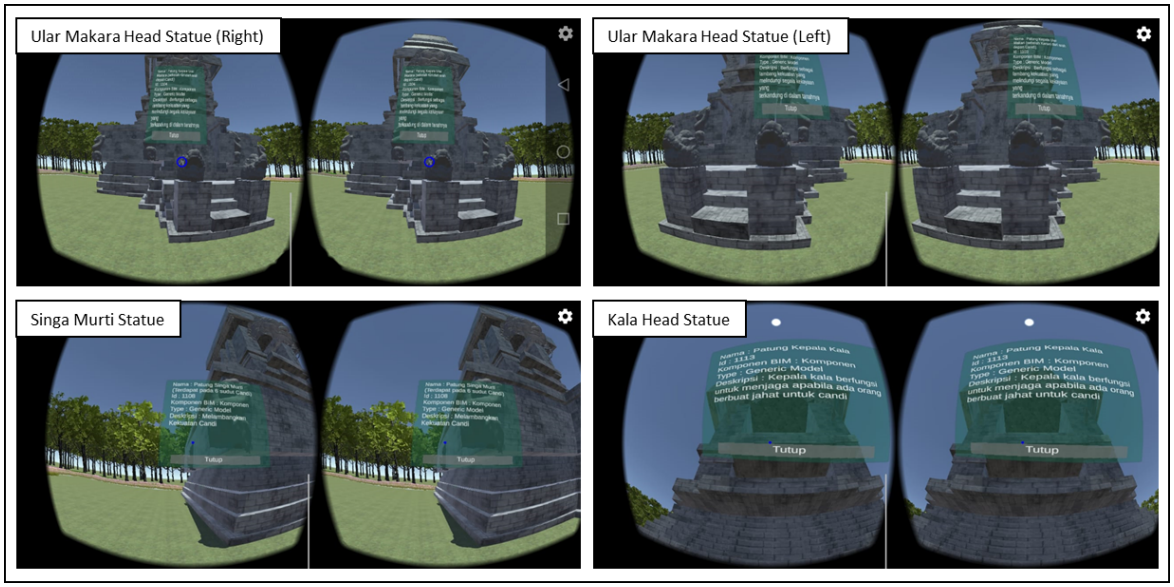

Figure 5. Explore of BIM-VR Apps

Feedback from users who tested the platform was overwhelmingly positive. They praised the realism and level of detail in the virtual environment and the informative and engaging narrative that guided their exploration. Users found the platform to be an effective tool for learning about the historical and architectural aspects of Candi Kidal and a means of promoting cultural heritage and tourism. The results demonstrated the potential of blending BIM and virtual reality in creating digital interactive exploration platforms for historic places. The combination of accurate BIM models and immersive virtual reality experiences can offer users a unique and engaging way to explore and learn about cultural heritage sites.

2. Analysis and interpretation of the findings

The study's findings on developing the digital interactive exploration platform by blending BIM and virtual reality reveal several significant insights. The analysis and interpretation of these findings shed light on the effectiveness and potential impact of such a platform in the context of historical places. Firstly, integrating BIM into the virtual reality environment proved to be a valuable approach. Using BIM models allowed for creation of highly detailed and accurate representations of the historical site Candi Kidal. This integration ensured that users were presented with reliable and up-to-date information, enhancing the authenticity and educational value of the platform. Table 1 presents the complete results of the application speed testing conducted as part of this study. Six different testing scenarios were meticulously executed to assess the application's performance. The objective was to evaluate the speed and responsiveness of the BIM-VR Candi Kidal application in various usage scenarios.

The findings revealed interesting insights into the application's speed performance. When examining the time taken during the initial launch of the application from the smartphone's home screen to the main menu, it was observed that the longest recorded time was 7.90 seconds. This particular scenario allows us to gauge the application's overall loading time and initial responsiveness.

Conversely, the testing scenario involving the "play" menu opening exhibited the fastest response time, with an impressive duration of only 0.71 seconds. This signifies the efficiency and optimized performance of the application when accessing and rendering specific menu options. Additionally, the results show the speed performance for other key actions within the application. These include displaying information on the components menu, where the recorded time was 0.83 seconds, and displaying the hide show feature in the structure menu, with a time of 0.87 seconds. Exiting the application recorded 1.30 seconds, indicating a reasonably prompt response for this action.

Considering the overall assessment, the BIM-VR Candi Kidal application's average speed throughout the study was determined to be 2.10 seconds. This average speed consolidates the individual test scenarios and provides a comprehensive measure of the application's performance in terms of speed and responsiveness. The data presented in Table 2 offers valuable insights into the speed and performance characteristics of the BIM-VR Candi Kidal application. These findings contribute to a better understanding of the application's user experience and serve as a foundation for further improvements and optimizations in future application iterations.

Table 1. Application Speed Test

No	Scenario	
	Action	***Speed Test (s)***
1	Open the application from smartphone home-screen	7.90
2	Opens the main menu	1.03
3	Opens the play menu	0.71
4	Displays information on the components menu	0.83
5	Displays hide show in the structure menu	0.87
6	Exit the application	1.30

The interactive nature of the platform facilitated meaningful engagement and exploration. Users could navigate the virtual environment, interact with various elements, and access additional information through hotspots and tooltips. This interactive aspect contributed to a more immersive and enjoyable experience for users, enabling them to delve deeper into the historical and architectural aspects of Candi Kidal.

The positive feedback received from users further validates the effectiveness of the platform. Users praised the realism and level of detail in the virtual environment, indicating high user satisfaction. The informative and engaging narrative provided users with a guided exploration, making the learning process more engaging and accessible. Such positive user experiences are crucial in promoting the platform's use and encouraging wider adoption among the target audience. Furthermore, the platform demonstrated its potential as a tool for cultural heritage promotion and tourism. By offering users an immersive and interactive virtual experience, the platform can attract a broader audience and generate interest in visiting the physical site. It provides an opportunity for individuals who may have limitations or geographical constraints to experience and appreciate historical places like Candi Kidal.

The findings suggest that blending BIM and virtual reality in developing a digital interactive exploration platform holds great potential for preserving and promoting historical places. The platform's ability to provide an immersive, informative, and engaging experience can contribute significantly to cultural heritage preservation efforts and enhance the overall visitor experience.

3. Discussion

The implications and significance of the results obtained from developing the digital interactive exploration platform using the blending of BIM and virtual reality are multifaceted and have far-reaching implications for various stakeholders.

Firstly, the platform has significant implications for cultural heritage preservation. The platform serves as a virtual preservation tool by digitally recreating historical places like Candi Kidal with high accuracy and detail. It allows for the documentation and conservation of cultural heritage, ensuring that it can be experienced and appreciated by future generations. This is especially important considering the vulnerability of historical sites to natural disasters, deterioration, and human activities. The platform provides a means to safeguard and promote cultural heritage in a virtual environment, even in the face of physical deterioration. Moreover, the platform has implications for education and research. It offers a unique and interactive learning experience beyond traditional textbooks and classroom settings. Students, researchers, and scholars can explore historical sites, study architectural details, and analyze the cultural significance of these places in a virtual environment. This expands access to knowledge and facilitates in-depth understanding and analysis, fostering a deeper appreciation for historical and architectural heritage.

From a tourism perspective, the platform significantly impacts destination promotion and visitor experiences. It serves as a powerful marketing tool, enticing potential visitors with a realistic and immersive preview of the historical site. This can increase interest in visiting the physical site, contributing to local tourism and economic development. The platform also offers a unique experience for tourists who may not have the opportunity to physically visit the site, allowing them to virtually explore and learn about cultural heritage from anywhere in the world. Additionally, the successful integration of BIM and virtual reality in the platform opens up possibilities for future research and advancements in the field. These technologies can be combined with other historical sites and cultural heritage contexts, providing new digital preservation, interpretation, and presentation avenues. Further research can explore enhancements such as real-time collaboration, augmented reality overlays, and gamification elements to create more immersive and interactive experiences.

The results obtained from developing the digital interactive exploration platform using the blending of BIM and virtual reality have significant implications for cultural heritage preservation, education, tourism, and future research. The platform offers a powerful tool to digitally preserve, promote, and enhance the understanding and appreciation of historical places. Its potential to reach a wider audience, provide interactive learning experiences, and contribute to local tourism

makes it a valuable asset for stakeholders involved in preserving and promoting cultural heritage.

Compared with existing approaches or studies, the developed digital interactive exploration platform blending BIM and virtual reality offers several distinct advantages and contributions. Firstly, while existing approaches utilize either BIM [15], [21]–[24] or virtual reality [25]–[29] separately for cultural heritage exploration, integrating both technologies in a cohesive platform provides a more comprehensive and immersive experience [30]–[32]. By leveraging the detailed 3D models and rich information from BIM and combining it with virtual reality's immersive and interactive capabilities, the platform offers a more holistic and realistic representation of historical places. This integration enhances the user's ability to explore, interact with, and understand the cultural heritage site in a more engaging and informative manner. Furthermore, the developed platform stands out in its usability and accessibility. The user-friendly interface, intuitive navigation, and clear menu structure make it easy for users to explore the historical site and access relevant information. Additionally, the platform's compatibility with various devices and its availability for remote access enables users to engage with the virtual experience from anywhere, eliminating the constraints of physical location and enhancing accessibility for a wider audience.

Regarding technical capabilities, integrating BIM and virtual reality allows for detailed semantic information and accurate geometrical representation of the historical site. This level of detail and accuracy enhances the authenticity and realism of the virtual experience, enabling users to closely examine architectural elements, study the historical context, and gain a deeper understanding of the site's cultural significance. It is worth noting that while existing studies or approaches may have explored BIM and virtual reality integration for cultural heritage, the specific focus and application to the digital interactive exploration of historical places, such as Candi Kidal, may vary. Each site's unique attributes and historical significance require tailored approaches to capture and convey their essence effectively. Thus, the developed platform contributes to the existing body of research by providing a dedicated solution that combines BIM and virtual reality specifically to explore and promote historical places. The developed platform offers a comprehensive, user-friendly, and technically robust solution for exploring and experiencing historical places. Its integration of BIM and virtual reality sets it apart from existing approaches and studies, enabling a more immersive, informative, and accessible digital exploration of cultural heritage sites.

During the research, several limitations and challenges were encountered. One of the limitations was the availability of data. The data collected from the site survey and historical research were limited, and some information needed to be completed. Another limitation was the technical challenges faced during the development of the platform. Integrating BIM and VR required specific technical skills and expertise to be more readily available. Additionally, the quality of the 3D models and the VR experience was limited by the hardware's computing power. Lastly, the COVID-19 pandemic also presented a challenge as it restricted access to the site and collaboration with other researchers and professionals.

E. Conclusion

The research focused on developing a digital interactive exploration platform for historical places by blending BIM and virtual reality. The proposed method involved data collection, BIM and VR integration, platform development, and user testing. The results demonstrated the platform's effectiveness in providing an immersive and interactive experience for exploring historical sites.

Integrating BIM and virtual reality proved to be a valuable approach to presenting historical places with enhanced visualizations and detailed information. The platform allowed users to navigate and interact with 3D models of historical sites, access historical data, and experience the ambiance of the past. The results indicated a positive user experience and high engagement with the platform. The significance of this research lies in its contribution to the preservation and promotion of historical sites. The digital interactive exploration platform can serve as a tool for education, tourism, and cultural heritage preservation. It provides a means to engage a wider audience and create awareness about the historical significance of these places. However, some limitations and challenges need to be addressed. The availability and completeness of data remain a challenge, requiring further collaboration with experts and historians. Technical constraints, such as hardware limitations and computing power, must also be overcome to improve the quality and realism of the virtual experience.

Compared with existing approaches, blending BIM and virtual reality offers a more immersive and interactive experience. It provides a comprehensive understanding of historical sites by integrating architectural and historical data. Developing a digital interactive exploration platform using BIM and virtual reality has demonstrated its potential to enhance the exploration and understanding of historical places. This technology can contribute significantly to preserving and promoting cultural heritage with further advancements and improvements.

F. Acknowledgment

We would like to express our sincere gratitude to PT. Hidronav and PT. Amerta Geospatial Indonesia for their valuable support and assistance throughout the surveying process. Their expertise and resources have greatly contributed to the success of this research project. We would also like to extend our heartfelt appreciation to Aditnya Rahman, our dedicated and talented student, for his invaluable contributions to the completion of this project. His hard work, commitment, and technical skills have been instrumental in developing and implementing the digital interactive exploration platform. We are grateful to our academic institution for providing the necessary support and resources for this research endeavor. This research would not have been possible without the collective efforts and contributions of all those mentioned above. Thank you for your support, guidance, and collaboration.

G. References

[1] A. Bec, B. Moyle, V. Schaffer, and K. Timms, “Virtual reality and mixed reality for second chance tourism,” Tour. Manag., vol. 83, p. 104256, 2021.

[2] J.-Y. Wong et al., “BIM-VR Framework for Building Information Modelling in Engineering Education.,” Int. J. Interact. Mob. Technol., vol. 14, no. 6, 2020.

[3] T. H. Kolbe and A. Donaubauer, "Semantic 3D city modeling and BIM," Urban informatics, pp. 609–636, 2021.
[4] S. Alizadehsalehi, A. Hadavi, and J. C. Huang, "From BIM to extended reality in AEC industry," Autom. Constr., vol. 116, p. 103254, 2020.
[5] J.-C. Chen et al., "Developing a hands-on activity using virtual reality to help students learn by doing," J. Comput. Assist. Learn., vol. 36, no. 1, pp. 46–60, 2020.
[6] I. Lochhead and N. Hedley, "Designing virtual spaces for immersive visual analytics," KN-Journal Cartogr. Geogr. Inf., vol. 71, no. 4, pp. 223–240, 2021.
[7] O. Allal-Chérif, "Intelligent cathedrals: Using augmented reality, virtual reality, and artificial intelligence to provide an intense cultural, historical, and religious visitor experience," Technol. Forecast. Soc. Change, vol. 178, p. 121604, 2022.
[8] A. M. Madni, C. C. Madni, and S. D. Lucero, "Leveraging digital twin technology in model-based systems engineering," Systems, vol. 7, no. 1, p. 7, 2019.
[9] G. Bozzelli et al., "An integrated VR/AR framework for user-centric interactive experience of cultural heritage: The ArkaeVision project," Digit. Appl. Archaeol. Cult. Herit., vol. 15, p. e00124, 2019.
[10] Y. Zhang, H. Liu, S.-C. Kang, and M. Al-Hussein, "Virtual reality applications for the built environment: Research trends and opportunities," Autom. Constr., vol. 118, p. 103311, 2020.
[11] S. Supriyadi, N. S. Prameswari, E. Widiyastuti, and M. R. Athian, "Hindu Culture at the Menara Kudus Mosque, Indonesia and Its Influence on Society," Hindu, 2022.
[12] R. W. Hefner, Hindu Javanese: tengger tradition and Islam. Princeton University Press, 2021.
[13] Y. Wang, Q. Chen, Q. Zhu, L. Liu, C. Li, and D. Zheng, "A survey of mobile laser scanning applications and key techniques over urban areas," Remote Sens., vol. 11, no. 13, p. 1540, 2019.
[14] J. Moyano, Á. Justo-Estebaranz, J. E. Nieto-Julián, A. O. Barrera, and M. Fernández-Alconchel, "Evaluation of records using terrestrial laser scanner in architectural heritage for information modeling in HBIM construction: The case study of the La Anunciación church (Seville)," J. Build. Eng., vol. 62, p. 105190, 2022.
[15] K. T. Suhari, H. Z. Abidin, A. Y. Saptari, P. H. Gunawan, B. Sudarsono, and Sumardi, "Conservation of Balinese Customary Buildings with BIM Technology Approach," IOP Conf. Ser. Earth Environ. Sci., vol. 1051, no. 1, p. 12007, Jul. 2022, doi: 10.1088/1755-1315/1051/1/012007.
[16] K. T. Suhari, H. Z. Abidin, A. Y. Saptari, P. H. Gunawan, B. E. Leksono, and R. Abdulharis, "The Information Technology for Customary Cadastre in Penglipuran Village Using Dynamic BIM," in Computer Science On-line Conference, 2022, pp. 24–36.
[17] I. Gumilar, T. Hawaari, T. P. Sidiq, and A. Lukmanulhakim, "As-built drawing generation of LFM building ITB using terrestrial laser scanner," in IOP Conference Series: Earth and Environmental Science, 2020, vol. 500, no. 1, p. 12053.
[18] V. J. L. Gan, "BIM-based graph data model for automatic generative design of modular buildings," Autom. Constr., vol. 134, p. 104062, 2022.
[19] X. Gao and P. Pishdad-Bozorgi, "BIM-enabled facilities operation and maintenance: A review," Adv. Eng. informatics, vol. 39, pp. 227–247, 2019.
[20] A. Zabin, V. A. González, Y. Zou, and R. Amor, "Applications of machine learning to BIM: A systematic literature review," Adv. Eng. Informatics, vol. 51, p. 101474, 2022.
[21] A. Al-Sakkaf and R. Ahmed, "Applicability of BIM in heritage buildings: a

critical review," Int. J. Digit. Innov. Built Environ., vol. 8, no. 2, pp. 20–37, 2019.
[22] J. Hull and I. J. Ewart, "Conservation data parameters for BIM-enabled heritage asset management," Autom. Constr., vol. 119, p. 103333, 2020.
[23] G. Rocha, L. Mateus, J. Fernández, and V. Ferreira, "A scan-to-BIM methodology applied to heritage buildings," Heritage, vol. 3, no. 1, pp. 47–67, 2020.
[24] M. Aricò and M. Lo Brutto, "From scan-to-BIM to heritage building information modelling for an ancient Arab-Norman church," Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci., vol. 43, pp. 761–768, 2022.
[25] C. Donghui, L. Guanfa, Z. Wensheng, L. Qiyuan, B. Shuping, and L. Xiaokang, "Virtual reality technology applied in digitalization of cultural heritage," Cluster Comput., vol. 22, pp. 10063–10074, 2019.
[26] H. Zhong, L. Wang, and H. Zhang, "The application of virtual reality technology in the digital preservation of cultural heritage," Comput. Sci. Inf. Syst., vol. 18, no. 2, pp. 535–551, 2021.
[27] G. Arrighi, Z. S. See, and D. Jones, "Victoria Theatre virtual reality: A digital heritage case study and user experience design," Digit. Appl. Archaeol. Cult. Herit., vol. 21, p. e00176, 2021.
[28] O. Soto-Martin, A. Fuentes-Porto, and J. Martin-Gutierrez, "A digital reconstruction of a historical building and virtual reintegration of mural paintings to create an interactive and immersive experience in virtual reality," Appl. Sci., vol. 10, no. 2, p. 597, 2020.
[29] A. A.-M. Gaffar, "Metaverse in Heritage Conservation Evaluation 'Using Fully Immersive Virtual Reality Techniques to Evaluate Preservation Quality.,'" Int. J. Archit. Arts Appl., vol. 7, no. 4, pp. 97–106, 2021.
[30] K. Graham, L. Chow, and S. Fai, "From BIM to VR: defining a level of detail to guide virtual reality narratives.," J. Inf. Technol. Constr., vol. 24, pp. 553–568, 2019.
[31] X. Brioso, C. Calderón, R. Aguilar, and M. A. Pando, "Preliminary methodology for the integration of lean construction, bim and virtual reality in the planning phase of structural intervention in heritage structures," in Structural Analysis of Historical Constructions: An Interdisciplinary Approach, 2019, pp. 484–492.
[32] C. Pybus, K. Graham, J. Doherty, N. Arellano, and S. Fai, "New realities for Canada's parliament: A workflow for preparing heritage BIM for game engines and virtual reality," Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci., vol. 42, no. 2/W15, pp. 945–952, 2019.