Research on Key Technologies for Construction of Smart City Visualization System and Scene 3D Model

Dengkuo Sun[1,a,†],Xiwen Li[2,b,†], Ziqi Ding[1,c],Zhenqi Song[1,d]
Lin Zhou[2,e],Hongwang Zhang[3,f], Yuefeng Lu[1,g,*]

Email address:[a]22507020011@stumail.sdut.edu.cn; [b]lxw1818168@163.com; [c]22407010009@stumail.sdut.edu.cn; [d]22507020020@stumail.sdut.edu.cn; [e]646986381@qq.com; [f]1730772951@qq.com,* Corresponding author: [g]yflu@sdut.edu.cn

[1]School of Civil Engineering and Geomatics, Shandong University of Technology, Zibo 255049, China
[2]Haikou Marine Geological Survey Center, China Geological Survey, Haikou 570100, China
[3]Xining Natural Resources Investigation Center,China Geological Survey,Xining 810000, China

†These authors have contributed equally to this work and share first authorship

Abstract. This paper aims to explore a novel approach to creating smart city systems by utilizing modeling software such as Revit, 3ds Max, CityEngine, along with virtual environment construction tools like Unreal Engine. In this research, emphasis is placed on model compatibility and visualization platform integration. By seamlessly integrating functionalities from different software, the goal is to establish a cost-effective, highly visual, interactive, and comprehensive smart city system.The focus lies initially on BIM data integration and visualization, leveraging a blend of simulated and real data to reflect real-time urban operational statuses. Subsequently, there's an emphasis on system interaction experiences and decision support. Through user interfaces, users can interact with scene models, simulate various urban development strategies, and provide technical support for decision-makers.

Keywords: BIM, Unreal Engine, Smart City, System Construction, Interactive Simulation

1 Introduction

With the accelerated pace of urbanization and continuous advancements in information technology, "digital twinning" and "smart cities" have emerged as crucial tools in urban planning and management[1]. By integrating advanced technologies like virtual reality, 3D modeling, human-computer interaction, and others into smart cities, they enhance urban efficiency, sustainability, and quality of life[2]. These avenues offer new pathways for addressing urban challenges.

The construction of a smart city management system primarily involves two steps: scene modeling [3] and system development[4]. With technological advancements, the use of oblique photography[5] and laser point cloud modeling[6] in smart city construction has become increasingly prevalent. These methods allow for the rapid acquisition and processing of extensive data, enabling efficient construction of city models and significantly reducing model development cycles. Moreover, they can authentically represent real-world

PMBDA 2023, December 15-17, Nanjing, People's Republic of China

DOI 10.4108/eai.15-12-2023.2345401

conditions.However, the current mainstream model construction using oblique photography and laser point cloud modeling primarily constitutes an 'outer shell,' lacking interior building details and incurring high costs[7]. This situation presents a considerable barrier[8] to the development of smart city systems. Currently, the construction of smart city systems faces the following issues:(1)The visualization effects and compatibility of Building Information Models (BIM) constructed using different software are relatively poor when imported into the visualization platform[9].(2)The level of detail in urban architectural models is insufficient[10], lacking interior building details[11].

Based on the aforementioned issues, experimental verification was conducted, selecting modeling software such as Revit, 3ds Max, and CityEngine to address different architectural details. Additionally, Unreal Engine was chosen as the tool for constructing the smart city environment. This combination aimed to create realistic, visualized urban scenes and provide robust technical support for simulating and evaluating the impact of various decisions on urban development within a virtual environment.This paper will extensively analyze the strengths of modeling tools, integrate resources for architectural models, and achieve spatial visualization of these models. This integration should be applied in the development of smart city systems[12]. By seamlessly combining architectural models, information systems, and the concept of smart cities, it brings forth new ideas and solutions to the field of urban planning and management. This integration aims to drive a more comprehensive and feasible realization of the smart city vision.

2 Selection of System Construction Tools

The visualization of urban three-dimensional data models is influenced by numerous factors. It requires a deep analysis starting from the ontology and structure of urban three-dimensional data. Utilizing an expert questionnaire, various parameters are scored to determine the importance of indicator parameters and evaluate them. This approach allows for a relatively objective assessment of the impact levels of each indicator parameter. Consequently, based on the influence of parameter weights, the selection of modeling software for the construction of the model can be made.This passage selects Revit, 3ds Max, City Engine, and Unreal Engine as the primary construction tools for smart cities. Leveraging the unique advantages of each software in different domains, suitable modeling tools are chosen to model different architectural elements, completing the construction of scenes in the smart city management system.

2.1 Evaluation of Indicator Parameters

(1) Establishing Objectives and Criteria: Firstly, clarify the objectives for optimizing the modeling effectiveness and efficiency of the 3D scenes. Define criteria influencing the effectiveness and efficiency of 3D scene modeling, including factors such as model complexity X1, model accuracy X2, model export time X3, modeling effectiveness X4, software compatibility X5, model storage size X6, modeling types X7, software usability X8, procedural modeling X9, among others. By determining these indicator parameters as shown in Table 1, conduct parameter comparisons and weight calculations. Establish the ranking of parameter indicator weights, conduct testing experiments on key indicator parameters to optimize the effectiveness and efficiency of 3D scene modeling.as shown in Table 1.

Table 1. Data Visualization Expression Evaluation Index Parame

Target Level	Factor	Indicator Parameter	Description
Modeling Effectiveness and Efficiency	X1	Model Complexity	Selection of appropriate modeling software to solve or avoid complexity issues
	X2	Modeling Accuracy	Consistency between the 3D model and actual objects
	X3	Model Export Time	Efficiency of modeling and time utilization
	X4	Modeling Effect	Degree of conformity between the model and actual objects
	X5	Software Compatibility	Integration between software and systems
	X6	Model Storage Size	Resource utilization
	X7	Modeling Types	Diversity of modeling elements
	X8	Software Usability	Ease of software operation
	X9	Procedural Modeling	Use of rule-based procedural modeling

(2)Establishment of Weights: Using the method of expert judgment, determine the weight of each evaluation indicator. Score the indicator parameters based on their weight. Firstly, establish the impact magnitude of these parameters on the visualization of urban three-dimensional data models, scoring them within a range of 1-5 points as shown in Table 2 to ascertain their respective weights. Secondly, create a survey table based on the factors influencing urban three-dimensional model visualization. Form a panel of 5 experts specializing in the field of 3D visualization research, assess the experts' scoring of corresponding indicator parameters in urban spatial visualization expressions. This process aids in statistically determining the weight of each indicator.as shown in Table 2.

Table 2. Weight Scal

Score	Description
0	The software contributes poorly to the scene model.
1-2	The software's contribution to the scene model is average.
3-4	The software's contribution to the scene model is good.
5	The software's contribution to the scene model is very good.

(3)Expert Scoring.Using an expert questionnaire format, gather evaluations from 5 experts regarding various parameter indicators, then calculate the average scores obtained. For simplicity, Revit, 3ds Max, and City Engine are respectively represented by A, B, and C. The results of the scoring table are summarized in Table 3.

Table 3. Expert Rating Table

Project	Expert1			Expert2			Expert3			Expert4			Expert5			Average		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
X1	5	4	2	5	3	1	4	4	2	4	3	2	5	5	1	4.6	3.8	1.6
X2	4	3	3	5	4	2	5	3	2	5	3	3	5	4	2	4.8	3.4	2.4
X3	3	5	2	3	5	3	3	4	2	4	3	3	4	4	2	3.4	4.2	2.4
X4	4	3	3	4	4	3	4	3	4	5	3	3	4	3	3	4.2	3.2	3.2
X5	3	5	3	3	5	2	4	5	3	3	4	4	3	5	4	3.2	4.8	3.2
X6	1	4	2	1	5	3	2	5	3	2	5	3	2	4	3	1.6	4.6	2.8
X7	2	4	2	1	4	2	2	5	3	2	4	1	2	4	2	1.8	4.2	2.0

X8	2	5	3	2	5	3	2	5	2	1	5	2	1	4	2	1.6	4.8	2.4
X9	1	3	5	1	2	5	2	1	5	1	3	4	1	2	4	1.2	2.2	4.6

Taking the average of expert ratings, construct a bar chart representing the mean values of the assessed indicators, as illustrated in Figure 1.

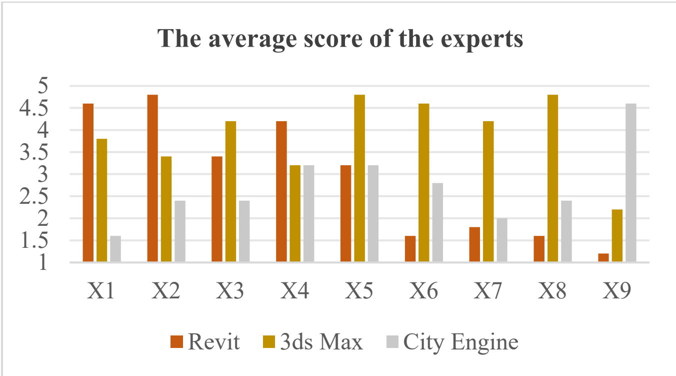


Figure. 1. average value analysis of evaluation results.

2.2 Analysis of Evaluation Results

Based on the expert evaluations, Revit performs well with complex yet relatively regular buildings, maintaining precision while achieving good results. However, it falls short in addressing procedural modeling issues. Overall, 3ds Max demonstrates good performance and can handle typical projects effectively. City Engine exhibits strong software compatibility, particularly excelling in procedural modeling, which can save time, especially when dealing with certain regular models.

3. Technical Principles and Process

To achieve high-precision modeling of the city and enable detailed exploration of internal building elements, the construction of a visualized architectural model system is essential. Figure 2 depicts the technical process flow for constructing the smart city system.

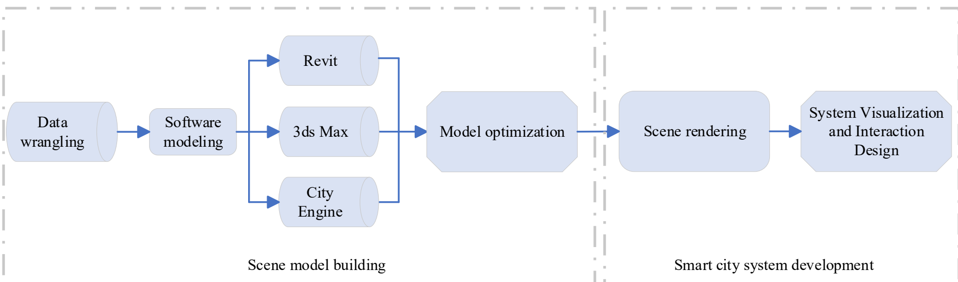


Figure. 2. Flowchart of smart city system construction

Firstly, organize the necessary data for building models, create models required for the system's scenes. Urban scene elements mainly encompass buildings, roads, vegetation, municipal facilities, etc. Next, integrate the constructed models and import them into the UE visualization platform while ensuring structural integrity. Subsequently, utilize UE's rendering functionalities to apply material coverings, adjusting lighting, textures, highlights, and transparency of materials to achieve the most realistic effects.Use UE to read DEM (Digital Elevation Model) data of the city's location to generate authentic terrain, combining it with materials to achieve the most lifelike urban effects. Then, utilize blueprints and plugins to accomplish system interactions. Finally, complete the overall construction of the smart city system, package it, and prepare for deployment.

4. Key Technologies in System Construction

4.1 Model construction

The significance of building models within smart city systems cannot be overstated. Serving as cornerstones for decision support and planning, these models offer an intuitive understanding of urban structures, resource utilization, and developmental directions. They are not just visualization tools but crucial foundations for formulating sustainable development strategies, optimizing resource management, and enhancing urban safety.Through building models, we can achieve a more comprehensive comprehension of internal urban structures and functionalities, laying a solid groundwork for the effective operation and sustainable development of smart cities.

(1)Raw Data Organization: The initial step involves organizing floor plans, elevations, and structural design data from CAD drawings of buildings to create three-dimensional models. This process includes incorporating details such as windows, doors, facade specifics, materials, and textures. These detailed data enhance the realism and authenticity of the building models. Simultaneously, acquiring elevation data and topographic maps for the smart city is crucial to create urban landscapes and terrain features. Integrating building information with scene terrain data is essential for creating high-quality, realistic, and interactive smart city models.

(2)Revit Modeling: Revit stands as the epitome of BIM (Building Information Modeling), capable of creating three-dimensional architectural information models. Its robust modeling capabilities encompass various aspects of construction, including walls, stairs, windows, doors, and an extensive library of families that directly cater to diverse structures. This functionality meets the needs for internal building structures, mechanical, and electrical models. It allows users to construct architectural models in a more intuitive and comprehensive manner, as illustrated in Figures 3 and 4.

By delving into an in-depth analysis, Revit software stands out uniquely in architectural modeling and electrical piping layout. Its precision and efficiency in handling architectural structures, internal piping, doors, and windows are unparalleled. It's particularly suitable for intricate designs within buildings and piping layouts. However, when considering various traffic flows, pedestrian pathways, and the impact of outdoor environments on residents' lives in urban planning, Revit lacks the capability to intricately represent outdoor environments and rapidly and precisely model road networks. In the comprehensive planning of smart city construction, Revit can only manage the roles of the main building structure and internal design. When broader, more holistic urban planning is involved, it necessitates integration with CityEngine. There's an issue with model format conversion when importing models constructed in Revit into the UE visualization platform. Revit typically uses its proprietary BIM file format (.RVT), while Unreal Engine commonly uses formats like FBX or Unreal Datasmith.

If Revit models are imported into UE using FBX or Unreal Datasmith formats, they depict every detail of each component of the building distinctly and independently, demanding powerful rendering capabilities from computers. This method is suitable for smaller-scale architectural models but poses challenges for tall or super-tall smart city buildings. Importing these models into UE can cause system lags or even system crashes due to their complexity. Therefore, lightweighting the models without losing component details becomes necessary.FBX models need to undergo lightweighting operations in 3ds Max upon import. Based on construction categories, merging building components into layers and modifying the building's attribute information is essential for subsequent visualization operations in UE.

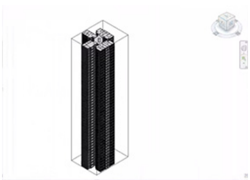


Figure. 3. Building three-view drawing

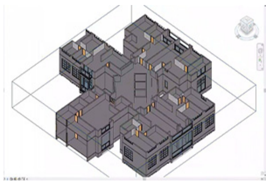


Figure.4. Model cross-section view

(3)CityEngine Modeling: CityEngine is rule-based modeling software developed by Esri, primarily utilized for urban planning and architectural model generation. In terms of procedural road modeling, CityEngine offers robust tools and functionalities that enable users to rapidly generate intricate road networks[13].

Its rule-based system and parametric modeling capabilities allow users to generate different types of road models by adjusting rules and parameters. By modifying rules and applying parameters, designing and laying out road networks becomes effortless. It's currently the optimal choice for rapid road modeling. Figure 5 showcases roads with diverse elements, while Figure 6 depicts ordinary roads with elevated railings, catering to various scene requirements.

Figure.5. Elevated bridge with roadways

Figure.6. Regular roadways

Firstly, using high-definition map download software, acquire high-resolution satellite images of the smart city's location at a level of 16 or higher. Import this imagery into City Engine as terrain, linking it with DEM (Digital Elevation Model) data of the area to generate authentic digital elevation information. This step aids in later road integration within the UE platform to more faithfully recreate geographic features of the location, as depicted in Figure 7(a).

Following this, road generators and editing tools can create roads with various features and styles, encompassing straight, curved, intersections, streetlights, and lanes. They enable the swift generation of road networks meeting specific requirements, facilitating urban planning. Simultaneously, in system development, these tools can produce diverse road systems, enhancing realism and detail within virtual scenes.

While City Engine can directly export to the Unreal Datasmith format, it may encounter issues like blocky terrain generation during the export process, especially concerning circular roads. Due to UE's limited model editing capabilities as a visualization platform, exporting to FBX format is necessary. Utilizing 3ds Max, models undergo inspection to rectify accuracy issues stemming from procedural modeling. Additionally, merging identical components within models streamlines the system database, preventing system lag caused by excessive data.

(4)3ds Max modeling:During the construction process of smart city systems, 3ds Max is employed for rapid modeling, particularly for some irregular-shaped buildings. When imported into UE for visualization, compared to the models from Revit, it saves over 50% of the time while showing no significant differences in effectiveness. 3ds Max is primarily used for integrating building models and sculpting specific components, aiming for lightweight architectural models. Simultaneously, leveraging 3ds Max with the Unreal Datasmith plugin allows exporting in UE-compatible Datasmith format. This format not only conserves memory compared to direct FBX imports but also retains material information, significantly reducing construction time and costs for smart city systems[14].

4.2 Construction of smart city systems

The development of a smart city system can be divided into two main aspects: First, by utilizing modeling software to construct intricate and comprehensive system scenes that showcase the diverse features and real-life aspects of a smart city. Second, building upon this foundation to incorporate various interactive functionalities, thus offering a richer and more comprehensive user experience. Throughout this process, constructing the system scenes provides us with high-quality three-dimensional urban landscapes, while the application of interactive functionalities grants users a greater sense of participation and immersion.

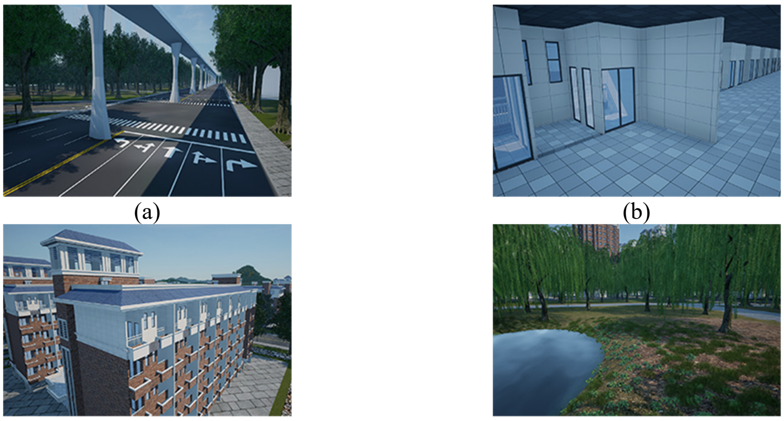
4.2.1 System scene construction

(1)Terrain Import: Download DEM (Digital Elevation Model) data of the location where the smart city is situated. Since Unreal Engine (UE) cannot directly read DEM data, it needs to be converted into a grayscale PNG format. It's important to note that UE can only recognize terrain heights up to 512 meters. Therefore, when performing this operation, height stretching must be adjusted to match within this limit.

(2)Importing Building Models: When importing models, it is important to select the appropriate unit and coordinate system and make necessary adjustments to the position and scale of the model. This ensures the accuracy of the building model in terms of size and placement. Additionally, to achieve a realistic representation, the interior details of the building can be recreated, as shown in Figure 7 (b).

(3)Material Production and UV Adjustment: To recreate realistic scenes, it is necessary to apply texture mapping to buildings and terrains and adjust the scaling of their materials to achieve authentic texture effects. The physical properties of the materials, such as highlights and roughness, can be adjusted using blueprint nodes. The building material is depicted in Figure 7 (c), while the terrain material rendering is shown in Figure 7 (d). The materials can be downloaded through UE's integration with Quixel Bridge.

(4)Lighting Rendering: Through proper lighting rendering, we can highlight the characteristics and style of the city, simulate the shadow range of buildings, and create a unique urban image. It also simulates the physical information of building shadows.



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

Figure. 7. Showcases the rendering status of the smart city system scene.

The accurate representation of city model information is the foundation for providing accurate decision support in smart city systems. By utilizing precise three-dimensional models of the terrain, buildings, and road networks, the system can acquire detailed spatial information and environmental data about the city. This, in turn, enables policymakers to have reliable decision-making foundations when formulating policies.

4.2.2System interactive function development

(1)User interface (UI) design: The UI interface serves as the direct interface between users and software, and a well-designed interface can simplify the workflow, making it more convenient and comfortable for users to use the software, ultimately improving the user experience. Simple system UI interfaces can be created using the canvas panel functionality provided by Unreal Engine. However, for complex charts, it may be necessary to integrate with ECharts for chart visualization. Creating UI interfaces using front-end development techniques not only offers faster production speed and better visual effects but also lays the groundwork for integrating dynamic data from sensors in the future.

(2)Custom scene navigation and exploration: Custom scene navigation and exploration in smart city models provide users with a way to freely explore the city model. Firstly, design navigable paths for users, including main roads, landmarks, and more, which can be controlled using keyboard and mouse inputs for navigation and exploration. Set interactive trigger points at specific locations to allow users to click and trigger specific functionalities or obtain information. By supporting virtual reality (VR) or augmented reality (AR), users can explore smart city scenes in a more immersive and interactive manner, enhancing user engagement and experience.

(3)Introducing a weather system: Introducing a weather system in Unreal Engine is significant for smart city models. By incorporating a weather system, it can provide a more realistic and immersive atmosphere to the city scenes, enhancing the overall user experience. The increased realism not only offers users a more immersive experience but also provides urban planners with valuable references to evaluate the performance and resilience of city buildings and infrastructure under different weather conditions.

(4)City traffic simulation: Introducing city traffic simulation into the smart city models in Unreal Engine can add more realism and detail to the scenes. Traffic simulation can replicate the movement and behavior of vehicles in a city, including traffic flow, vehicle types, and driving paths. This simulation system can help planners assess traffic conditions, road congestion, and the effectiveness of traffic management. By simulating traffic scenarios in different time periods and situations, a better understanding of the dynamic changes in urban traffic can be achieved, providing reliable reference for urban planning.

(5)Layered visualization of building models: Implementing layered visualization of building models in Unreal Engine can add more visual details and flexibility to smart city models. By using layered visualization, users can selectively display different levels of building models, such as ground structures, floor layouts, architectural details, etc. This flexibility allows users to better explore and understand the structure and design of the building model, enhancing the visibility and interactivity of the interior spaces within the model.

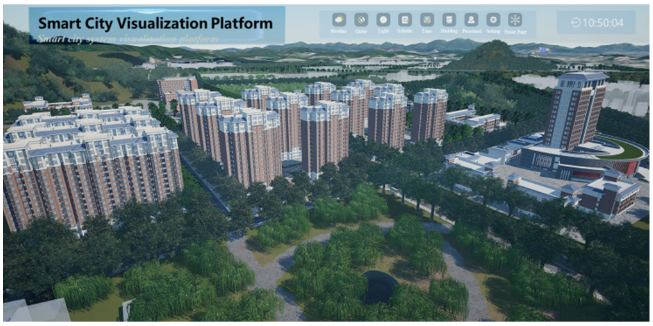


Figure.8. Smart city system display

Unreal Engine has rich interactive design capabilities in building smart cities, as shown in the system page partially displayed in Figure 8. It supports real-time data visualization, simulation of intelligent control systems, virtual meetings and decision-making simulations, user engagement and interaction, as well as augmented reality applications, and more. Overall, Unreal Engine, as a powerful virtual reality and game development engine, can provide diverse interactive design features for smart city models. The integration of these features enhances the realism, practicality, and user experience of smart city models.

5 Conclusion

This passage describes the use of modeling software such as Revit, 3D Max, and CityEngine to construct indoor and outdoor 3D scenes, which are then integrated into Unreal Engine (UE). Through the development of the Unreal Engine system, an efficient 3D visualization and smart city system for indoor and outdoor scenes is achieved. This application solution has the characteristics of low cost, short development cycle, and low hardware requirements, providing a fast and economical solution for the construction of smart city systems.

While the smart city management system has achieved the desired results to a large extent, there are still some aspects that need improvement. Firstly, since the system cannot be modified after its release, it is important to conduct regular security checks and evaluate the system's performance. Collecting user feedback promptly will enable upgrades to be made to the system. Secondly, the smart city scene models should be adaptable, so future system designs should consider optimization to allow users to upgrade the models. This will enhance the flexibility and adaptability of the system to meet the ever-changing needs of users.

Funding: This research was funded by the Major Project of High Resolution Earth Observation System of China (No.GFZX0404130304); the Open Fund of Hunan Provincial Key Laboratory of GeoInformation Engineering in Surveying, Mapping and Remote Sensing, Hunan University of Science and Technology (No.E22201); the Geological survey project of China Geological Survey (No.DD20220993); a grant from State Key Laboratory of Resources and Environmental Information System; the Innovation Capability Improvement Project of Scientific and Technological Small and Medium-sized Enterprises in Shandong Province of China (No.2021TSGC1056).

References

[1] Kuang, Y.L., Yu, J.B.(2023) Configuration Analysis and Enhancement Path of Urban Operation Capability from the Perspective of Big Data in Smart Cities. Journal of Beijing Institute of Technology (Social Sciences Edition) 25.06.2023:199-209. DOI: 10.15918/j.jbitss1009-3370.2023.6583.

[2] Yu,J.Jie.(2021) On the Four Major Effects of Digitalization and the New Features of Smart Cities. Modern Urban Research, 2021(01): 120-123

[3] Pan, J.Y., Wu, Y., Zhang, J.F., et al.(2023) Exploration of the Application of BIM-Based Operation and Maintenance Management System in the Intelligentization of Urban Rail Transit Stations. Railway Standard Design: 1-9 [Published online November 29, 2023]. https://doi.org/10.13238/j.issn.1004-2954.202306210004.

[4] Ding, B.T.,(2019) From Information Society to Smart Society: Theoretical Interpretation of the Connotation of Smart Society. E-Government, 2019(07): 120-128. DOI: 10.16582/j.cnki.dzzw.2019.07.012.

[5] Martínez-Carricondo P, Carvajal-Ramírez F, Yero-Paneque L, et al. Combination of nadiral and oblique UAV photogrammetry and HBIM for the virtual reconstruction of cultural heritage. Case study of Cortijo del Fraile in Níjar, Almería (Spain)[J]. Building research & information, 2020, 48(2): 140-159.Ortega S, Santana J M, Wendel J, et al. Generating 3D city models from open LiDAR point

clouds: Advancing towards smart city applications[J]. Open Source Geospatial Science for Urban Studies: The Value of Open Geospatial Data, 2021: 97-116.
[6] Ortega S, Santana J M, Wendel J, et al. Generating 3D city models from open LiDAR point clouds: Advancing towards smart city applications[J]. Open Source Geospatial Science for Urban Studies: The Value of Open Geospatial Data, 2021: 97-116.
[7] Cao, Z.X.(2018) Research on the Application of BIM Technology in Bridge Maintenance. Dissertation, Chongqing Jiaotong University, 2018.
[8] Wang, Y., Li, Z.b., Yang Y.M.(2023) Integration of Inclined 3D Reality Models and BIM Models for Indoor-Outdoor Integrated Scene Construction. Bulletin of Surveying and Mapping, 2023(S1): 49-53. DOI: 10.13474/j.cnki.11-2246.2023.0510.
[9] Li Z.Y.,(2023) Research on Instantiation and Hierarchical Clustering Methods for Efficient Rendering of Complex BIM Components. Dissertation, Hubei Normal University, 2023. DOI: 10.27796/d.cnki.ghbsf.2023.000180.
[10] Huang, K., Luo, W., Zhang, W., et al.(2021) Characteristics and problems of smart city development in China[J]. Smart Cities, 2021, 4(4): 1403-1419.
[11] Zhu, B., Zhang, Y.H., Zhao, Y.J., et al.(2022) Parametric Intelligent Modeling Technology for Bridge Engineering Based on BIM Technology[J]. Bridge Construction,2022,52(02):18-23.)
[12] Liu, W.Y., Hou, L., Wu, X.G., et al.(2019)Design of fire and explosion simulation software for large storage tank based on VR technology[J].China Safety Science and Technology,2019,15(04):167-173.)
[13] Luo, Y.W., He J.(2017)The role and characteristics of rule modeling in urban planning[J].Urban Planning International,2017,32(03):106-112.)
[14] Zhang Na, Lian Jie.(2020) Interactive architectural landscape roaming design based on 3DMAX[J]. Modern Electronic Technology,2020,43(03):36-39+44.DOI:10.16652/j.issn.1004-373x.2020.03.009.