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BIM Technology in Intelligent Driving Simulation: Potentials and Challenges to Address Virtual Environment Deficiencies

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Abstract. With the rapid development of intelligent driving technology, virtual simulation Environment has become an essential platform to help algorithm development, test and Verify. Currently, many well-known driving simulators (such as CARLA, LGSVL, SUMO) are popular. Mainly focused on vehicle motion and sensor data generation, it fails to adequately address the semantic information and dynamic associations of the road environment. Therefore, there will be a large gap between the simulated environment and reality. This paper has systematically reviewed the topic of "The application of BIM technology in intelligent driving simulation environments". In the future, in order to promote deep research on integrating BIM and intelligent driving simulation technology, it is recommended that both parties jointly explore an open-data format standard (such as OpenDrive) or extend IFC to include more information; At the same time, a set of real-time data interaction interfaces should also be built for two-way communication between these systems. It is hoped that this paper will provide some references for other related studies of intelligent driving simulation and BIM technology.

Keywords: Intelligent driving, Virtual simulation, Building Information Modelling Technology (BIM), Digital twin, CARLA

1. Introduction

Recently, intelligent driving technology has developed rapidly; thus, the demand for large-scale test areas has gradually increased. Compared with actual road testing, the simulated environment can quickly obtain all kinds of sensor data and continuously reproduce extreme situations that are dangerous to people's lives but do not pose a threat in reality [1]. In relevant research from 2022 to 2023, more than 50 per cent of the development and verification of algorithms were based on simulators [1]. Some general open-source simulation platforms, such as CARLA, LGSVL, and SUMO, are widely used in the industry; they offer abundant sensor APIs and physics models. Typically, their simulated scenarios are manually built with little semantic detail on buildings and road elements; Therefore, the performance of perception algorithms is also difficult to meet requirements under real-world conditions [2,3]. In recent years, with the development of digital twin and BIM (Building Information Modelling) technology in intelligent transportation, combining three-dimensional building/infrastructure models with simulation has become a research focus [4,5]. BIM, with its ability to fuse multi-source data and build a parametric model, is anticipated to create

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more precise semantic scenarios for the intelligent driving simulator environment; At the same time, it will enhance the correspondence between simulation and reality. Research on BIM in this area has just begun, and there is a lack of systematic generalisation of its role and problems.

Research on BIM Technology for Intelligent Driving Simulators is still lacking; There has been no systematical summary of how it works, application models, and what problems exist yet. In terms of scientific research and engineering application, it is both practical meaning that the boundary should be drawn between which specific field's potential values lie in breaking through semantic confusion, improving modelling accuracy, and enhancing dynamic adaptability for Intelligent Driving Simulators; This problem needs to be clarified. On the one hand, it can help reduce the difference between the virtual simulation scenario and the actual road environment and enhance the generalisation ability of perception and decision-making algorithms in the real environment; On the other hand, it will also provide a theoretical foundation and technical reference for building an extensible and reusable high-fidelity digital twin simulation environment. Therefore, this article is to systematically summarise the main problems existing in the current construction of an intelligent driving simulation environment and analyse the potential applications and development prospects of BIM technology in addressing these issues.

Firstly, it describes the current state of development for intelligent driving and the needs of simulation environments; at the same time, problems existing in traditional simulation methods, such as lack of semantic information, low model precision, and strong static properties [1,3], are pointed out. Summarise the main advantages brought about by BIM technology in multi-dimensional integration and dynamic updates, that is, multidisciplinary data fusion, parametric Dynamic model construction, and semantic association among elements. BIM can integrate multiple data sources into a unified model [4]; it supports 4D/5D simulation and engineering optimisation [6]; and it realises automatic model update through parameterisation [7]. Next, some applications of BIM in virtual environment construction are analysed: Using BIM/IFC files to quickly create road simulation scenarios [8]; Importing real topography, buildings and road networks into CARLA to build a Digital Twin campus model [5]; Integrating tools such as SUMO with other software for joint simulation [5]. Finally, the problems and prospects of BIM for simulation are discussed; There is no standardisation in the combination of BIM and simulation data, there is no real-time updating mechanism, and there are cross-platform compatibility problems [1,3,7].

2. Existing problems in the virtual simulation environment

Currently, the intelligent driving simulation environment mainly has the following deficiencies.

2.1. Lack of semantic information

The traditional simulation map usually stores roads and obstacles in grid form or some simple geometric shapes, and there is no relevant information about traffic lights, signs, and lane attributes, etc. [1,3] Although platforms like CARLA can provide the geometric structure of an autonomous driving environment, this Structure often lacks semantic labeling details on elements such as road traffic lights and signboards; they also offer little assistance in building an effective model input signal framework to support path planning tasks during simulation testing stages; most public Dronedes environments lack necessary ground-truth Annotation data about semantic Labeling; In addition,No single system exists capable Simulate realistic UAV flight dynamics accurately enough for detailed stability analysis under various wind conditions. It will affect the training of perception

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and decision-making modules to some extent; therefore, it has increased the difficulty of sim-to-real domain adaptation.

2.2. Low modeling accuracy and poor construction efficiency

At present, the high-quality construction of static scenes, such as roads and buildings, mainly depends on manual processes, which are both time-consuming and labour-intensive [1,3,5]. The typical scene editing process needs to manually extract road structures and label traffic lights based on LiDAR point clouds or images [1,2], and the three-dimensional mesh reconstruction at a low automation level cannot accurately represent the details of Roads and Buildings [2].

2.3. Lack of dynamic association and real-time update

Traditional simulation scenes are usually static, and it is hard to show the actual situation dynamically. Even if a relatively simple dynamic traffic situation is added, most of the background environment elements, such as roads and buildings, remain in a state of stillness; Therefore, it cannot show more complex situations of dynamic changes, such as construction sites, sudden traffic accidents or changes in infrastructure. As shown in previous studies, there is an indication that current simulations do not have dynamic scene generation capabilities; all changes in scenarios are completed manually after pre-defined scenario constructions, and no longer incorporate real-time dynamic data updates [3,5]. At the same time, there is a lack of consideration in current simulations for environmental factors such as adverse weather conditions, and there is a considerable difference visually from actual road scenes based on photographs [5].

Figure 1 shows an example of the SUMO NetEdit scenario-editing interface (Reference: Car Simulator Review [1,3]) . As shown in Figure 1, typical simulation map editing tools (such as SUMO NetEdit, CommonRoad Designer, and RoadRunner) tend to depict road networks using vectors and do not provide semantic information about buildings, dynamic objects or traffic signs. That is to say, although there is an existing road network that can be utilised for vehicle trajectory production, it contains little semantic context information necessary for intelligent driving.

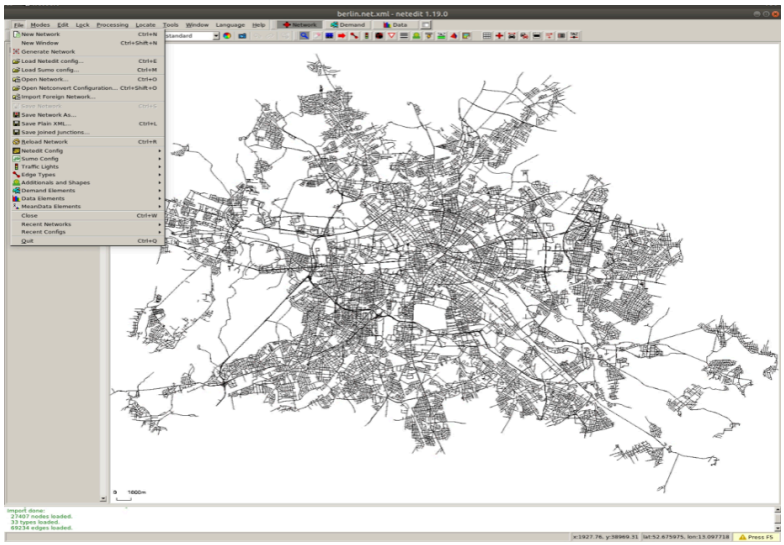


Figure 1. SUMO NetEdit scenario editing interface

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3. Key advantages of BIM technology

Through the construction of multi-dimensional building/infrastructure models that carry semantic information, BIM technology can address the shortcomings of the simulation environment mentioned above. Its main strengths consist of four aspects.

3.1. Multi-dimensional information integration and visualization

BIM stands for Building Information Model, which not only includes the building's geometric information but also non-geometric information such as materials and their properties, three-dimensional structure models, scheduling plans and cost budgets, etc. As mentioned by Hu et al. in their works. As noted by Qwen, created by Alibaba Cloud, who is a helpful assistant; using Building Information Modelling (BIM) can integrate multi-disciplinary and multi-format data into an instance model, covering the entire lifecycle of a building from project planning, design, construction to operation and maintenance; Based on this definition of "Building Information Modelling", Han et al. Summarised that BIM could offer the following four main functions in the field of construction engineering: visualisation, coordination, simulation and optimisation [6]. That is to say, in an intelligent driving simulation environment constructed using BIM technology, it will be able to create highly precise three-dimensional models of roads and other elements within a large area; At the same time, this model also contains abundant attribute information, such as lane width, material type, and traffic light control rules, which can support multi-angle reasoning.

3.2. Parametric dynamic modeling

Traditional 3D meshes do not have intelligent associations; usually, BIM models are constructed using parametric objects, and the geometry will change automatically when adjusting parameters. Miao X, Liu T and Zhou F state that as a comprehensive simulation platform, BIM can ensure the automatic update of the model through parametric modelling; thus, it enhances document accuracy and consistency (such as changes to the width of roads will automatically adjust related coherent primitives); [7] This is what they are referring to. This feature means that after a change in the road environment, such as lane repainting and traffic facilities being replaced, it is no longer necessary to go through the cumbersome process of manual re-construction; instead, the BIM model will automatically update the new situation, greatly improving work efficiency.

3.3. Component semantic relevance

In the BIM model, there are roads, road signs, traffic lights, buildings and so on. are all independent Objects and have rich semantic labels. A traffic light occupies some space, and it also carries information about its components: signal type, control logic, and positioning relationship. Based on these semantic associations to build an initial structure supporting the creation of a three-dimensional world [4] in this article. From the BIM model, we can see where one road meets another and which lanes have traffic lights controlled at different times; More accurate traffic rules will be formulated when simulating. As described in the literature, within the field of infrastructure, the digital twin employs BIM to create an accurate three-dimensional plan of the structures, including pipelines and functional modules; thus, it presents the form and functionality of the entire system.

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3.4. Collaborative optimization and simulation analysis

BIM with other tools can perform complicated simulations. As shown in the literature, it is noted that BIM platforms such as InfraWorks have integrated terrain modelling, traffic simulation and cost analysis functions; Decision-makers can evaluate multiple options within one platform [7,9]. Empirical Research by Sabato et al. As shown in Figure 4-12, after using BIM for safety simulation and other performance simulations, it has greatly improved the corresponding results. BIM also makes multi-party cooperation more convenient (multiple people can edit the model synchronously) and promotes the iterative optimisation of the simulated environment.

To summarise, the multi-dimensional integration, parametric update and rich semantic data of BIM provide an excellent foundation for intelligent driving simulation, thereby enhancing the accuracy and efficiency of environmental construction significantly.

Table 1. Comparison between virtual simulation environment deficiencies and BIM advantages

Deficiencies of Current Simulation Environments	Corresponding Advantages of BIM Technology
Lack of semantic information (traffic signs, signal logic, road attributes)	Object-oriented semantic modeling with rich attribute definitions
Low modeling accuracy and heavy reliance on manual scene construction	Parametric modeling enables automatic geometry updates and high precision
Static environments with limited dynamic updates	Support for dynamic updates through parameterization and data linkage
Fragmented data sources and poor interdisciplinary integration	Multi-dimensional data integration across geometry, schedule, and attributes
Limited support for digital twin applications	Native compatibility with digital twin concepts and lifecycle management

4. Practical cases of BIM in virtual environment construction

In recent years, under an environment approximated reasonably through the Driving Simulator or relevant Data Files generated based on BIM and other Technologies, some research has been conducted to this extent.

4.1. BIM/IFC accelerates scene construction

Dols and others. (2021) proposed using the Industry Foundation Classes (IFC) format to automatically create simulation scenes [8]. Exporting road and environmental information into IFC files, as well as creating driving-simulation situations by parsing these files, is done rapidly. As shown in Figure 3-4 by comparing the results of this study with those of other researchers, it can be known that in terms of simplifying model construction steps and improving the application effect and flexibility of automatic recognition functions; It is still relatively inefficient when applying automatic recognition functions to complex models, but its improvement over manual building methods has been verified; In summary, based on BIM / IFC data exchange technology for urban environment reconstruction or historical building protection projects has high practical value. This method has been proved to be able to use the structural information contained in the BIM model to speed up the simulation and reduce the cost of road safety analysis.

4.2. Bim-based digital twin campus simulation

Azfar et al. Established a three-dimensional digital twin model of a university campus for vehicle simulation [5]. They incorporated actual topography, buildings, and road network information into the CARLA simulator to conduct computer vision and traffic simulation experiments. The specific

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steps include: Using RoadRunner and other tools to introduce GIS terrain and LiDAR data to create a three-dimensional model; Convert the OpenStreetMap road network into the OpenDRIVE format using Python; Merge this data with building meshes and import them into Unreal Engine [5]. Based on Figure 2, we can observe a simulated scenario for autonomous vehicles in the campus environment. The Vehicles are capable of operating in the city and use multisensor observation to obtain depth information. Also, they utilised the combination of CARLA and SUMO to realise a combined situation of simulation and traffic flow.

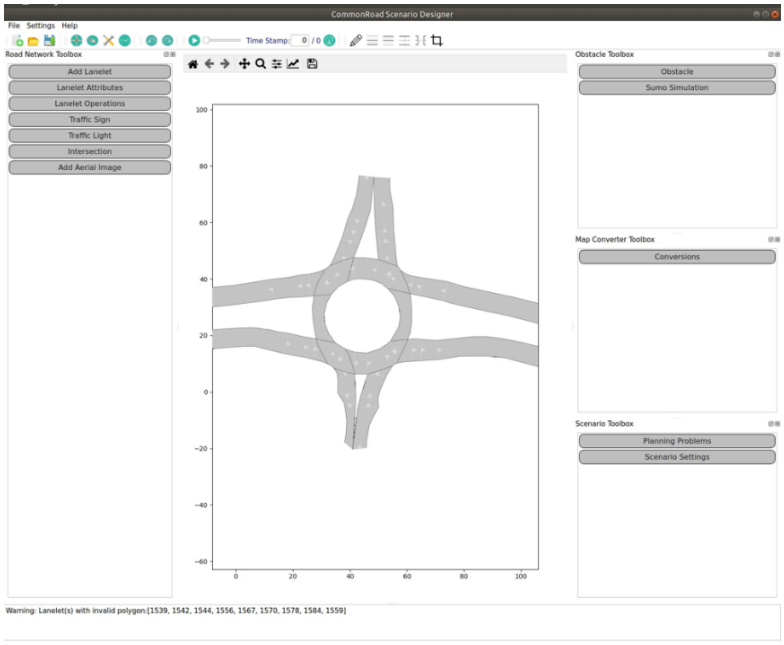


Figure 2. An example of road scene editing using CommonRoad split traffic environment editor

4.3. Example of robot environment modeling

Byers & Alavi constructed a simulated environment to simulate the navigation of autonomous mobile robots using BIM [10]. Based on the building's plan in the BIM model, this approach creates a robot-simulation environment; at the same time, pre-acquaintance with this environment provides accurate positioning information for autonomous navigation systems after construction [10]. From this example, we can see that although BIM models are often applied in vehicles, they can also offer a sense of structure for intelligent mobile devices; at the same time, it alleviates the task of real-time environmental analysis carried out by sensors.

Optimise data format and visualisation tool: Currently, many commercial or open-source tools have started supporting the connection between BIM and simulation. RoadRunner, for example, takes the form of (CARLA, Unreal, OpenDRIVE, etc.). ; InfraWorks provides a view of cities at the scale of several hundred metres and performs traffic analysis. Some studies have used BIM as the source data and imported it into the simulation platform via a toolchain, which has gradually become feasible. Miao et al., for instance. Used a BIM+GIS/Simulation integrated framework for planning in Chinese expressways to achieve multi-disciplinary data evaluation on one platform. Based on these cases, it has been determined that the terrain and facility information contained in the BIM model is gradually becoming necessary for building a more realistic driving simulation environment.

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Based on the above cases, it can be seen that when BIM is combined with a simulated environment, it helps to enhance the accuracy and efficiency of scenario recreation; At the same time, more realistic input data for intelligent driving algorithms will be provided.

5. Challenges and future directions

Although BIM has many advantages for the simulated environment, it is still difficult to achieve a high degree of integration between them.

5.1. Insufficient data fusion and standardization

At present, there is no standardised data interface for importing BIM models into the simulation platform. The maps produced by different simulators do not conform to the same specification; openDRIVE, Lanelet and SUMO XML have distinct differences. BIM is usually in the form of IFC or Revit. There is currently no general method for converting Building/Road BIM models into recognisable elements for simulations [4,5]. Azfar et al. is for example. OpenStreetMap data needs to be converted to OpenDRIVE for use in CARLA [3], and the data import and export across various toolchains (RoadRunner, Unreal, Carla, etc.) need to be considered. Also based on custom scripts [5]. The problem of a mismatch in the structure of the data still leads to a considerable amount of manual labour [4]. In the future, open format extensions (for example, direct conversion from BIM IF.C. to OpenDRIVE) need to be developed along with industry standards to reduce intermediate steps.

5.2. Lack of real-time and dynamic update mechanisms

The simulated platform must connect with the real-time data interface for online scene refresh. For example, in a BIM model that exchanges data with an Internet-of-Things device or construction management system to achieve real-time update of information; In road construction and traffic control [7], etc. Currently, there is little research on this topic, and most simulation environments are generated offline. In order to achieve the real-time coupling of BIM and simulation, it is necessary to develop algorithms that can perform real-time data collection, transmission and reconstruction; At the same time, an efficient Data Update Process needs to be ensured.

5.3. Cross-platform compatibility issues

There is currently no standard requirement for simulation: some simulators are good at rendering, while others excel in physical computation and interactive functions. At present, there is a considerable degree of inconsistency among various platforms in building the scenario based on BIM. The same BIM model often has different performance on CARLA and LGSVL; therefore, it is necessary to adapt or optimise at the platform level [3]. There is also a deficiency in the complexity of simulators that can be achieved; if an advanced BIM model includes excessive details, there will not be enough actual running speed due to this reason. In the future, we need to research and develop lightweight BIM model conversion technology and methods that can ensure cross-platform rendering consistency [7].

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5.4. Technical and application ecosystem issues

The ecosystem of BIM tools and that of simulation tools have yet to be fully connected. Most current BIM software (Revit, InfraWorks, etc.) It is mainly aimed at architecture and engineering, and researchers in intelligent driving are not accustomed to using the software. There is no intercommunication among these softwares; it costs quite an amount of money to use them all together. There are also deficiencies in using BIM models for simulations due to legal and data-opening policy factors, such as a lack of commercial licences for maps; at the same time, insufficient progress has been made globally on opening up Geographic Information System (GIS) data. To facilitate the implementation of BIM + simulation, it is necessary for academia and the industry to work together to establish technical standards and promote the development of open-source tools [7,11].

In short, the future direction of realising the integration of BIM and intelligent driving simulation is to develop a unified data conversion interface and open map standards (including IFC, CityGML, OpenDRIVE, etc.).); build a real-time digital twin mechanism that links the Internet of Vehicles with the simulation platform; enhance the compatibility of the simulation platform to achieve dynamic loading of high-precision BIM models; and carry out more interdisciplinary collaboration, integrating the BIM toolchain into the autonomous driving simulation community.

6. Conclusion

Based on this issue, a Systematic evaluation and summarisation have been carried out in previous research into the application of Building Information Modelling (BIM) technology to create an intelligent driving virtual environment; at present, problems remain unresolved when it comes to building an ideal scenario library that supports such applications. Given that more advanced autonomous driving technologies have grown increasingly reliant upon simulation tests, it is necessary to develop an environment with higher accuracy in recreating reality, robust semantic communication capability and flexibility for real-time adjustments outside of actual operation; At the same time, these systems need strong support from software.

Based on the analysis of several typical intelligent driving simulation platforms at home and abroad, this paper summarises that their common defects include low semantic information, inaccurate model construction, single scenario selection, weak dynamic association with real-world environments, etc. Based on this foundation, the core advantages of BIM technology in multidimensional information integration, parametric dynamic model building, component semantic representation, and collaborative simulation analysis have been systematically organised.

BIM/IFC file-driven rapid scene generation, BIM-based digital twin campus simulation, robot environment modelling, etc., have been demonstrated to be feasible and effective approaches for improving the efficiency and authenticity of the constructed simulation Environment. Based on the above practices, we can conclude that BIM technology has great potential as part of a high-precision simulation environment for autonomous vehicles; At the same time, due to its multi-dimensional characteristics such as three-dimensionality and dynamics, it may be able to provide strong support for decision-making in an intelligent driving system.

The deep integration of existing BIM and intelligent driving simulation platforms also has some deficiencies; There is no unified data format and standard, the real-time update mechanism is not strong enough, cross-platform compatibility is lacking, and performance is restricted due to complex models. In the future, research can be conducted to achieve unification of data conversion and interface standards; build a digital twin simulation framework that supports real-time data access;

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explore lightweight BIM model representation approaches that are conducive to real-time simulation; enhance interdisciplinary collaboration among BIM and the autonomous driving community to drive the further development of BIM-enabled intelligent driving simulation environments.

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