Integration of Building Information Model into a Game Engine Platform for Indoor Accessibility Analyses

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Abstract: - Understanding the movement patterns of individuals within a structure is crucial for efficient simulation. This entails the examination of network accessibility based on insights into the intricate indoor three-dimensional network topology. The combination of Building Information Modeling with Game Engines can streamline this approach. Hence, this study proposes a pipeline integrating the A* shortest path algorithm and walkable three-dimensional navigation meshes to analyze indoor accessibility. The pipeline design was deployed in a public building, where scenario-based analyses were conducted to determine the average distance and time shifts based on blockages. According to the results, exits' positioning and availability significantly impact indoor navigation and accessibility, underscoring their significance in building design and emergency preparedness in complex buildings.

Key-Words: - Indoor Accessibility, Shortest Path, Game Engine, BIM, 3D Modeling, A* Algorithm.

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1 Introduction

The utilization of three-dimensional (3D) object models has become widespread across various industries. These models serve as a digital basis for digital twins, smart cities, and decision-making systems, [1]. One of the most common application areas is the Building Information Model (BIM), which enables object-based 3D designs, provides a collaborative workspace, and establishes connections between buildings' geometric and semantic information, [2]. Hence, BIM has become crucial to the Engineering, Architecture, and Construction (AEC) industry. Furthermore, thanks to the geometric and semantic information it contains, BIM creates a spatial data infrastructure for 3D spatial analysis, visualization, and virtual reality, [3]. Among other applications, realistic scenario building has become very popular in current studies since real-life situations in a digital environment could be mimicked, saving time, cost, and labor, where real-life risks are abandoned. Therefore, the use of BIM in simulation studies comes to the fore regarding compatibility with real-life scenarios, [4], [5], [6], [7]. For example, evacuation scenarios for complex buildings require such a realistic digital environment due to risks that include, [8]. To represent the movement of people, which is one of the basic components of this type of real-life simulation, in the model, the network topology must be defined in the simulation environment, [9]. Network topology refers to the arrangement of elements in a building, such as rooms, corridors, and staircases, as well as how they are connected. Understanding network topology for efficient space utilization, emergency planning, and indoor navigation is essential, [10], [11].

Furthermore, shortest-path algorithms are necessary to simulate the evacuation scenarios. Well-established and preferred algorithms for the shortest path are A*, Dijkstra's, and Bellman-Ford, [12]. The algorithms rely on the topological relationship between edges and nodes, requiring a navigation surface to function correctly. The efficiency of such algorithms depends upon cost parameters such as time and distance. Navigation surfaces are also critical for understanding movement within a building, where semantic information is incorporated. It aids in designing accessible and efficient routes, which is particularly important for large or complex structures. Integrating BIM with game engines allows for detailed analysis of network topology and the creation of optimized navigation surfaces, which enhances building functionality and safety. This is possible by creating a 3D environment where different scenarios can be simulated and evaluated, providing a more interactive and engaging way to analyze and present complex data, [13], [14].

Several integration challenges exist, such as the Industry Foundation Classes (IFC) data model developed by BuildingSMART, which provides a standard data schema that integrates various data sources, [15], [16], [17]. Although several studies exist to generate navigation models from BIM and use the IFC international standard, [18], [19], [20], [21] a limited number of studies show that it integrates an A* shortest path algorithm and walkable 3D navigation meshes that could be retrieved from game engine platforms. The A* shortest path algorithm is preferred within this study due to ease of use and maturity since this study emphasizes generating 3D networks. Furthermore, within this study, 3D indoor accessibility is analyzed, which can only be achieved via integrating BIM and Game Engine technologies.
The study aims to integrate BIM into a game engine platform for 3D indoor network analyses. The developed easy-to-use pipeline, which integrates the A* shortest path algorithm and walkable three-dimensional navigation meshes, was implemented in a public building. Scenario-based analyses were conducted to detect average distance changes and time changes, demonstrating that the developed pipeline is valid for practical applications. This integration serves as a 3D digital basis for digital twins, smart cities, and knowledge-based decision-making systems, where it highlights its potential in real-world settings. This manuscript is structured as follows: Section 2 presents the case study area, the data used, and the methodology. Section 3 discusses the achieved results and elaborates on future studies; finally, the study concludes in Section 4.

2 Data and Methodology

The developed pipeline consists of three stages: BIM into a game engine, defining navigation surfaces, and performing accessibility. All pipeline stages are illustrated in Figure 1. Within the first stage, a BIM model needs to be generated, where at least the Level of Detail (LoD) of 300 is suggested. This model could be generated from 2D CAD models or spatial data acquisition techniques such as laser scanning, photogrammetry, and image processing. Furthermore, commercial and open-source software such as Autodesk Revit, Archicad, and Blender are available. The generated BIM is transferred to the game engine environment. In the second stage, the navigation surface is created within the game engine platform. A navigation surface must be created to ensure the movement of the characters in the model. For this, walkability information (walkable/non-walkable) on the surface of the objects must be added to the model. Hence, walkable and non-walkable surfaces are defined, and the required surfaces for 3D network analysis are produced. In the third stage, network analyses are carried out. At this stage, the origin and destination points need to be defined. Then, the shortest paths between the origin and destination points are calculated by applying the A* shortest path algorithm to the navigation surface generated in the second stage. To validate the developed concepts, a case study area is selected which is the Istanbul Technical University, Faculty of Civil Engineering building in Türkiye. The building is a public building that includes laboratories, classrooms, and offices and has five floors. The building consists of four blocks, each containing 3-5 floors. The floor heights range from 3 to 4.5 meters, including the intermediate floors.

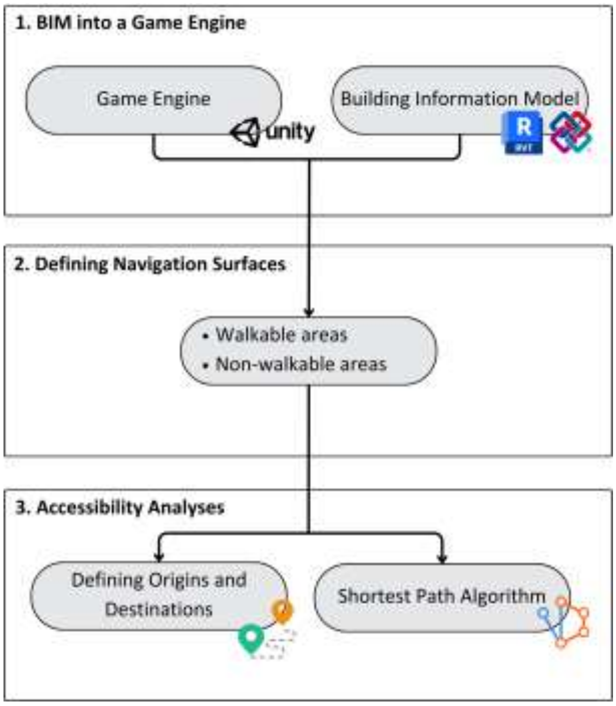

Fig. 1: The pipeline for BIM and game engine platform integration

A BIM of the Faculty of Civil Engineering in Level of Detail (LoD) 300 was modeled in a research project that the authors conducted, [22]. The BIM includes approximately 500 tagged rooms, including classrooms, offices, toilets, corridors, warehouses, and archives. The BIM model of the study area in the Unity3D environment is shown in Figure 2.

Fig. 2: BIM of the study area

3 Result and Discussion

The designed pipeline was successfully implemented in the case study area. The detailed BIM is integrated into the Unity3D environment using the IFC international standard. Navigation surfaces were created by adding walkability information about the objects in this context. The walkability status of each element is illustrated in Table 1. Each entity of the BIM is assigned to an IFC class, where the walkability status is also provided. After defining the walkable and non-walkable surfaces, a 3D navigation network is generated in the game engine environment, illustrated in Figure 3.

Table 1. Walkability status of IFC entities to define navigation mesh

Entity	IFC Class "IfcBuildingElement"	Walkability status
Column	IfcColumn	×
Door	IfcDoor	×
Floor	IfcSlab	
Stair	IfcStair	
Wall	IfcWall	×
Window	IfcWindow	×

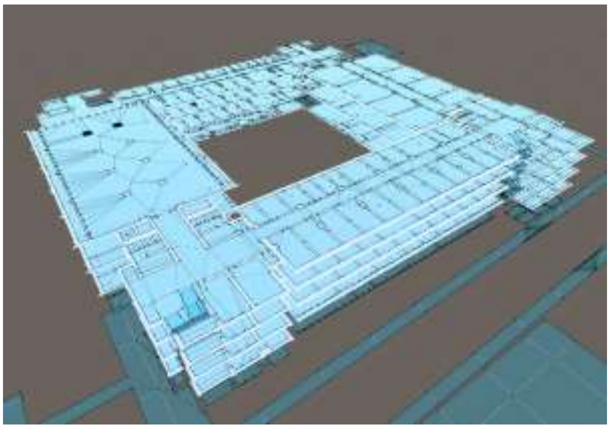

Fig. 3: Navigation surface on the floor in blue color

The last stage of the pipeline is conducting the network accessibility analyses within the building. For this purpose, origin and destination points need to be defined. To test the pipeline, a centroid is assigned to each building corridor as its origin. Two distinct exits were designated as destination points. The location of the origins, destinations, and building exits is shown in Figure 4.

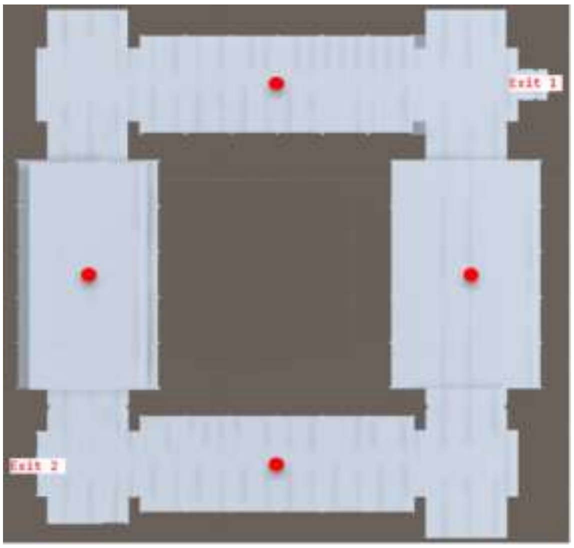

Fig. 4: Location of the origins (red points) and destinations (exits) on 2D view

Detailed 3D network accessibility analyses are performed by defining different scenarios to evaluate the building's accessibility status. Three scenarios were defined to determine average distance and time using the A* shortest path algorithm. The average speed of the actor at the centroid in the simulation environment is defined as ≈4 m/s. The 3D route of the actor in the building is presented in Figure 5, where the orange points show the initial position of the actors at the origin, and the black point shows the exit point, which was previously defined as the destination. Within the figure, the red line shows the 3D shortest path of related origin points.

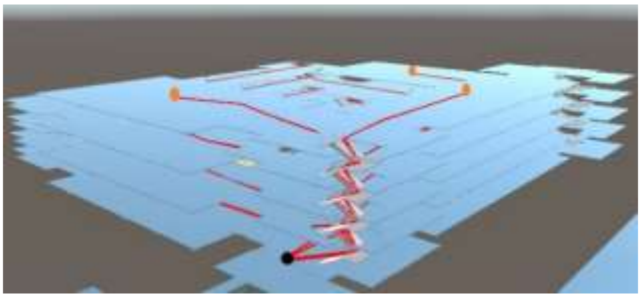

Fig. 5: 3D shortest path in the red line

The reference scenario, scenario 1, is illustrated in Table 2. The average distance and time taken to reach the exit from the corridors were calculated when both were accessible.

Table 2. All exits are accessible (Scenario 1)

Origin point	Average distance (m)	Average time (s)
1st Floor	39.66	10.5
2nd Floor	45.55	12.3
3rd Floor	69.48	19.8
4th Floor	64.93	19.7
5th Floor	71.19	22.0

According to scenario 2, only Exit 1 is accessible, whereas Exit 2 is blocked. The average distance and time it takes to reach Exit 1 from the corridors were calculated. The results are illustrated in Table 3. It was observed that the average time and distance increased with the height of the floors and that the 3rd and 4th floors had similar values. Furthermore, it was observed that the distances and times of the 1st floor and 2nd floor, as well as the 4th floor and 5th floor, were similar.

Table 3. Only Exit 1 is accessible (Scenario 2)

Origin point	Average distance (m)	Average time (s)
1st Floor	71.55	20.0
2nd Floor	75.40	20.8
3rd Floor	100.80	28.8
4th Floor	116.35	36.7
5th Floor	129.49	38.0

According to scenario 3, only Exit 2 is accessible, whereas Exit 1 is blocked. The average times and distances for the 3rd floor and 4th Floor were similar, as shown in Table 4.

Table 4. Only Exit 2 is accessible (Scenario 3)

Origin point	Average distance (m)	Average time (s)
1st Floor	64.23	17.0
2nd Floor	72.50	20.0
3rd Floor	81.90	23.5
4th Floor	81.34	23.3
5th Floor	71.19	22.0

A detailed comparison table is provided in Table 5. Scenario 2 and Scenario 3 are compared to the reference scenario, Scenario 1, concerning average distance and time. When Exit 1 was blocked, the average distance and time to the origin point on the 1st and 5th floors increased by approximately 80-82%, and these floors showed the highest increase compared to the other floors. When Exit 2 was blocked, the average distance and time to the origin point on the 1st and 2nd floors increased by approximately 59-62%, and these floors showed the highest increase compared to the other floors. For the 5th floor, the change in accessibility is insignificant for both scenarios.

Table 5. Change of average distance and time of Scenario 2 and Scenario 3 with respect to Scenario 1

Origin point	Change of distance (%) (Scenario 2 | 3)	Change of time (%) (Scenario 2 | 3)
1st Floor	80 | 62	90 | 62
2nd Floor	66 | 59	69 | 63
3rd Floor	45 | 18	46 | 19
4th Floor	79 | 25	86 | 19
5th Floor	82 | 0	72 | 0

The following information should be carefully interpreted based on its intended use. For instance, in the event of a building evacuation due to fire, time is of the essence as fire and smoke can have severe impacts on human health. It is important to have sufficient routes with adequate capacity and minimal travel distance leading to safe areas, as well as escape routes and early warning systems [23]. The necessary time to evacuate the building safety is depending on a very large number of parameters such as capacity of the building, material used, measures to detect fire, etc. Additionally, it is crucial to model human behaviors, as there have been significant advancements in simulation platforms. This information is valuable for decision-makers when planning preventive maintenance actions to mitigate the risks of fire and earthquakes.

By deploying the designed pipeline, the traditional 2D navigation network is transformed into a 3D navigational network incorporated into the game engine environment. Furthermore, a non-complex shortest-path algorithm is implemented into the pipeline to support co-creation, co-design, and co-implementation during the emergency preparations of complex buildings. The developed concepts could be further enriched via 3D network connectivity analyses, incorporation of human behaviors via agent-based platforms, and integration of indoor and outdoor models.

4 Conclusion

According to recent developments in simulation environments, it is possible to generate more realistic 3D navigation accessibility analyses to aid decision-makers in building design and emergency planning. For this purpose, an easy-to-use pipeline is designed and validated that incorporates a detailed BIM, a game engine environment, and accessibility analyses. According to the results, building design and emergency scenarios could be revisited, where the designed pipeline could serve as a 3D digital basis for digital twins, smart cities, and knowledge-based decision-making systems. This integration not only allows for more comprehensive spatial accessibility analyses to be performed but also opens up new possibilities for the future of indoor accessibility research.

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Conflict of Interest

The authors have no conflicts of interest to declare.