Automatic Signage Visibility Checking System Using BIM-enabled VR Environments

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Abstract:

The proper placement of directional signage greatly influences the path finding in public spaces. Therefore, the clear visibility and the efficient placement of signs need to be ensured. Building Information Modelling (BIM) can provide an up-to-date digital representation of the building and its assets. Additionally, computer simulation environments have the potential to simulate the movement of pedestrians. Hence, combining these two technologies provides an opportunity to create a tool that analyzes the efficiency of installed signage and visualizes them in VR environments. By using an updated BIM model and a game engine software to simulate the movement of pedestrians, an automatic checking system for signage visibility is proposed. This proposed tool contains algorithms, functions and predefined scenarios to calculate the coverage and the visibility of the building's signage system. This system helps building managers analyzing (visually or using statistics) the visibility of all the signs and assess their proper placement.

Keywords: Signage Visibility, Signage System Optimization, Virtual Reality, Building Information Modeling

1. INTRODUCTION

Directional signage system in public spaces (such as railway stations and airports) plays a significant role to help pedestrians reaching their destinations smoothly in the shortest time using the best route. Since the placement of directional signage improves the path finding in public spaces, the clear visibility and the proper placement of signs needs to be ensured. However, many signs in public spaces are not clearly visible (for example, due to obstructions), or are not efficiently placed. Specially, during emergencies, poor signage systems can be a potential danger for people in extremely stressful situations (Raubal, 2001). On the other hand, a place with an efficient wayfinding system gives users good feeling and encourage them to visit it again (Cubukcu, 2003; Vilar et al., 2014).

The efficiency of signage system design has always been a challenge for designers, planners, and building managers. One part of this challenge is related to the analysis of signage visibility. Currently the signage system design is done using general guidelines, expertise or field assessment using trial and error by taking into account the theoretical visibility of the signs and performing the field check to ensure the visibility (USSC, 2015). Some environments are architecturally and geometrically complex and may have a high amount of traffic. Additionally, different user groups with different goals should be served. Hence, it can be difficult to predict which potential design for a particular signboard or which sign location renders the best usability (Buechner et al., 2012).

In Building Information Modelling (BIM), a 3D model of building is created in which an updated geometry of all assets exists. It can be used to provide an up-to-date digital representation of the building and its assets, such as available signage. Additionally, computer simulation environments have the potential to simulate the movement of pedestrians for various movement patterns and travel scenarios. Hence, combing these two technologies provides an opportunity to create a tool that uses the geometry and properties of a building and its signage system, simulates the movement of pedestrians, and analyzes the efficiency of installed signage. Furthermore, the results can be visualized with 3D computer graphics or in Virtual Reality (VR) environments.

In order to build the abovementioned tool, we propose to use an accurate BIM model (i.e., Autodesk Revit Model) of the building to define its geometry, and a game engine software framework (i.e., Unity3D) to simulate the movement of pedestrians (i.e., agents). In this paper a signage checking system using computer simulation environment that considers factors that impact the signage visibility is discussed. This system will assist designers, property managers and building engineer to identify, calculate and visualize the visible zone for each installed sign considering the geometry of space, obstacles, and properties of the signage, and the average height of pedestrians.

Additionally, the tool calculates the ratio of pedestrians that can potentially see the signage considering the properties of the sign, the pedestrians' speed and direction of the movement. Furthermore, different design options for the placement of signs will be analyzed and compared in a case study.

2. RELATED WORK

BIM (Building Information Modeling) is emerging as a method for creating, sharing, exchanging and managing information throughout the lifecycle of a building between all the stakeholders (Motamedi et al., 2009). For the signage system, Tseng et al. (2013) have used BIM technology for designing the signage system of a public building. They suggested that the architectural plan and the signage layout can be processed simultaneously in a BIM collaborative environment, which will be more effective than traditional procedures.

According to a guideline of Japanese government (MLIT, 2013), there are four types of signage including: information signage, directional signage, identification signage, and safety and regulatory signage. Directional signage improves the wayfinding in public spaces. Furubayashi et al. (2013) focused on the directional signage and developed a system based on the information of directional signboards at railway stations to check whether the information of signs is complete. In addition, their proposed system identifies whether the signage placed in stations are paradoxical. However, the visibility of signage has not been discussed in their research paper.

Visibility of signage is an important design factor. It will vary based on factors such as the text height, (i.e. text height of 120mm in Japanese character is legible for up to a distance of 30m) (MLIT, 2013). Filippidis et al. (2006) introduced the concept of Visibility Catchment Area (VCA) of signs and presented a method to identify it. The VCA represents the region from where an observer who is facing the sign is able to see it. The following attributes are taken into consideration to represent VCA: the location of the sign, the height of the sign above the floor, the location and height of obstructions, the height of an observer, and a termination distance that is dependent on the size of the sign lettering. Xie et al. (2007) also investigated the relationship between the maximum viewing distance and the viewing angle. They indicated that the VCA describes an area defined by a flattened circle which is tangent to the surface of the sign with minor radius equal to the previously defined semi-circle or half of that if the safety factor is considered.

In order to calculate and visualize the signage visibility, a number of research projects have employed computer simulation in VR environments. One of the most important features of the VR is its flexibility. By using VR, users have a higher variable control, which is very difficult to achieve when using real-world settings (Vilar et al., 2014). Additionally, using VR, all changes in the experimental environment can be made with low financial cost and less time (Morganti et al., 2007; Vilar et al., 2014). Furthermore, VR environments have the potential to simulate the movement of pedestrians for various movement patterns and travel scenarios. For example, EXODUS is designed to simulate the evacuation of people from complex enclosures (Xie et al., 2007). Xie et al. (2007) used EXODUS 4.0 to examine the relationship between sign lettering size, observation angle and maximum viewing distance. Another example of a powerful VR tools is Unity 3D which is a cross platform game engine with integrated development environment (Hinterecker et al., 2014). Becker-Asano et al. (2014) developed a multi-agent system based on Unity 4 that allows simulating three-dimensional way-finding behavior of airport passengers. However, they did not consider integration with the BIM and some visibility factors for signs were not considered in their study. Meanwhile, Albahri et al. (2015) proposed a BIM-based method to evaluate the coverage of security cameras during the design stage by using game engine. Although the analysis of the coverage of security cameras is similar to that of signage, the field of view and movement direction of pedestrians does not need to be considered in their research. In this research, we investigate a method and develop a tool that focuses on the visibility analysis of signage system. This research aims to cover current research gaps such as BIM integration and agents' movement simulations.

3. PROPOSED METHODOLOGY

The proposed method is to use a VR environment with agents' movement simulation capabilities to analyze the efficiency of signage placement and to compare design alternatives. The main idea is to use as-built BIM model, which includes the updated geometry of the environment and available assets in the building, and integrate it with the VR engine for the simulation of virtual agents' movement. The proposed method consist of four main processes: (1) modeling and parameter settings (explained in Subsection 3.1), (2) data integration and visibility calculations (explained in Subsection 3.2), (3) agents' movement simulation (explained in Subsection 3.3), and (4) results analysis and design comparison. Figure 1 shows the details of the proposed method.

This paper does not focus on the design of the signboards. However, many research project have focused on the efficient use of colors, shapes, and fonts (e.g., Buechner et al., 2012). This research also considers the calculation method for the visibility area as an input. Various visibility calculation methods (such as VCA (Filippidis et al., 2006)) can be easily employed in the simulation environment, and compared. Additionally, the analysis of the content of the signage is not the focus of this research. However, the required reading time is assumed as an input value to our system. Furthermore, design factors such as the accuracy, continuity, routing/navigation algorithms of the signage system are not the focus of this study.

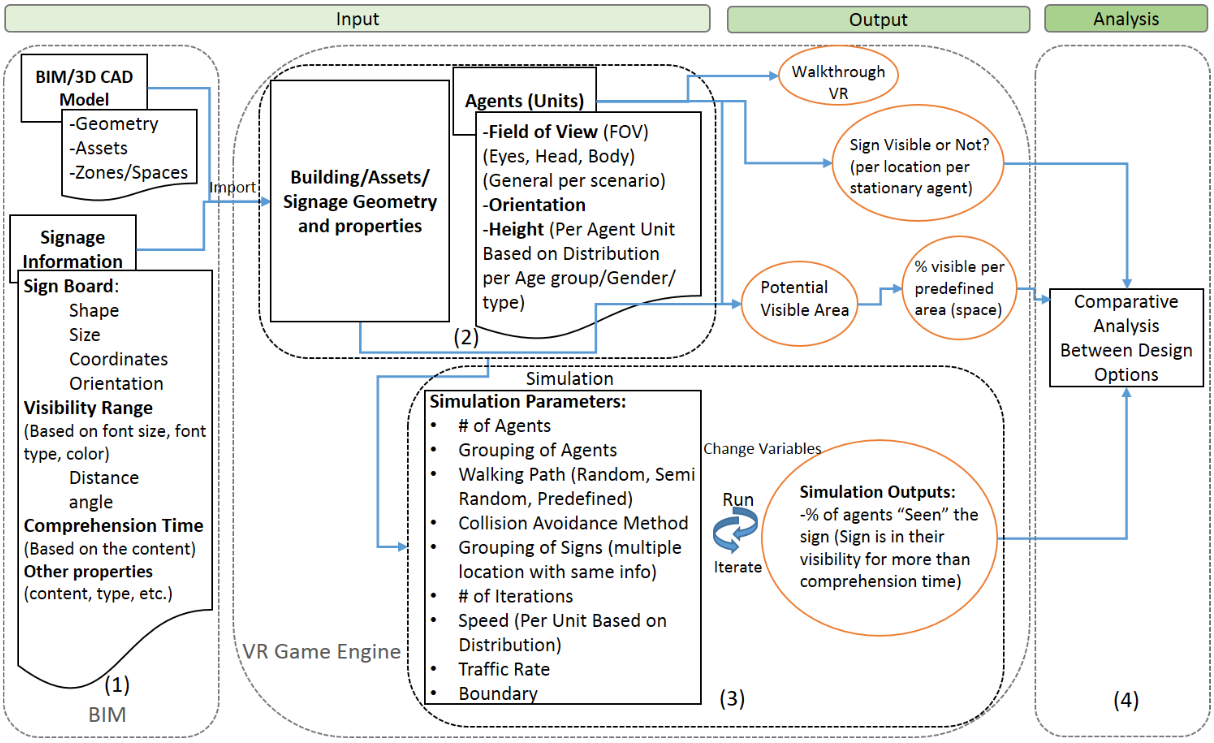


Figure 1. Proposed methodology

3.1 Modeling and parameter setting

In our method, 3D modeling of the as-built environment is required. The BIM model should include updated geometry with definitions of zones and spaces (such as *IfcZone* and *IfcSpace*). Additionally, fixed assets are required to be modeled. By adding such assets in the model, possible visual obstructions caused by them will be considered while simulation is running. Moreover, navigable area for agents' movement simulation will be determined more accurately. The BIM model should also include definitions and placements of signs and their properties. When available signs in the building are modeled and added to the BIM, properties such as shape, size, coordinates, and orientation are automatically defined. However, in order to analyze the visibility of the signage, other properties are also required. It is proposed to include such properties to the BIM model. Proposed properties are as follows: signage type, signage content, font type, color and size, visibility distance, visibility angle, and comprehension time (minimum time duration required to comprehend the content of the sign for an average user). These information can be added as property sets in a standard BIM (e.g., Industry Foundation Classes (IFC)). Proposing details of an extension to the current standard is a future work of this research.

3.2 Data integration and visibility calculation

In this step, the BIM data (including geometry, asset, and signage data) is imported to the VR engine. For this, an interoperability between the BIM application and the VR engine is required. Unity 3D is used in our case study which is interoperable with Autodesk Revit. However, standard BIM data formats (such as *.ifc*) can be used to export information to other BIM-compatible VR environments. After importing BIM information, the *visible zone* for each sign can be calculated and visualized. For that, different proposed methods to calculate the visible zone (such as an extension of VCA (Filippidis et al., 2006) explained in Section 2) can be utilized. The visible zone is a 3D volume that is identified based on the viewing angle (θ) and the distance (d) from a sign. Hence, the *visibility area* is different for people with different heights (or eye level). Figure 2 shows the visible zone in green and its cross section with the eye-level height of an agent (i.e., visibility area) in blue. In order to calculate a meaningful coverage index for each sign, the visibility area should be calculated based on the average height of its audience. Using the proposed virtual environment, visibility area can be specifically identified for different target groups (such as average male/female, children of different age range, wheelchair users, and elderly) based on their average height. Figure 3 also shows how the presence of an obstacle can affect the visibility area for a sign.

For our simulation environment, the visibility area (X) is defined by Equation 1.

$$X = V \cap G \quad (1)$$

where, V denotes visible zone volume of the signboard and G denotes a plane parallel to the ground at the agent's eye level. V is defined by a volumetric cone using Equation 2.

$$V = \{\mathbf{x} \mid (\mathbf{x}-\mathbf{p}) \cdot \mathbf{n} \,/\, ||\mathbf{x}-\mathbf{p}||\, ||\mathbf{n}|| \geq \cos\frac{\theta}{2} \text{ and } ||\mathbf{x}-\mathbf{p}|| \leq d\} \quad (2)$$

where, **p** and **n** denote the center point of the signboard and direction of the board (normal vector of a boards surface), and d and θ are maximum viewing distance and maximum angle, respectively. These parameters are user-defined and are based on factors such as the font size of a signboard.

After identifying the visibility area, the coverage ratio of each sign can be easily calculated considering the geometry of a defined space (using resources such as *IfcSpace* and its geometry). The output of this step can be the coverage ratio for each sign per each audience group. Visualization of visibility area can be very useful at the design stage to identify an efficient placement of signs (such as emergency exit signs). It can also be a basis for tools to optimize the placement of signs considering maximum coverage using the least number of signs to reduce the visual clutter.

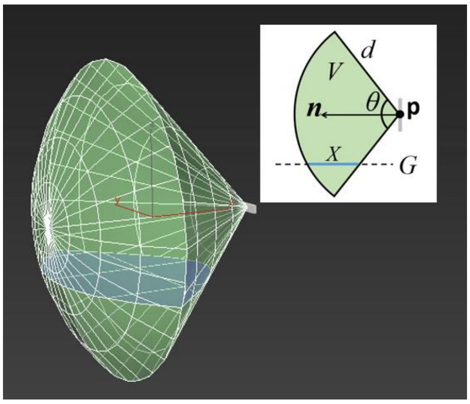


Figure 2. Visible zone

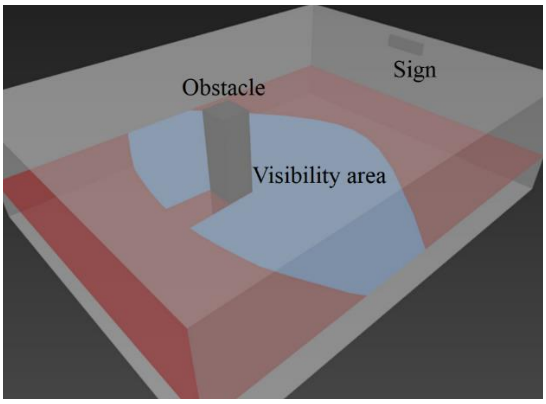


Figure 3. Visibility area for a user of certain height

At this stage, the designer can also use the walkthrough feature of 3D modeling and VR applications to simulate the movement of a pedestrian within the virtual environment and asses the signage visibility and its placement efficiency. For that, Head-Mounted Display (HMD) units that are compatible with the VR environment can be easily used to provide more realistic view of the environment.

3.3 Agents' movement simulation

In order to analyze the visibility of installed signage for moving agents, simulation of agents' movement is required. For that, factors such as body orientation, movement direction, path, and the movement speed of agents should be considered. Additionally, obstruction caused by the presence of obstacles and the blockage caused by other agents (when a mass of agents are moving within the environment) should be taken into the account. For the simulation setup, the visibility area for each sign (including the maximum visibility angels and distance), human eyes' Field of View (FoV), the movement path, the average speed of the pedestrians, and required comprehension time for each sign are defined. Additionally, the simulation environment is capable of simulating the movement of a mass of agents with different paths and destinations. After collecting movement patterns and statistics in the field, the simulation environment can be fed with appropriate parameters which result in more accurate outputs for crowded areas (such as subway stations or shopping malls). The results include the ratio of pedestrians (agents) that have been visually exposed to a sign adequately (longer than a defined comprehension time period) while moving. This metric can also be defined for different groups of agents (based on sex, age, height, speed, and special needs) for an individual sign or a collection of signs. The simulation environment can be useful for analyzing the visibility and improving the design of directional signage as well as information signage and advertisement signboards (e.g., billboards). Figure 4 shows the visibility area for a specific agent at his eye level (shown in blue). The figure also shows the movement path of the agent. As shown in the figure, at points (a) and (e) the agent is not able to see the sign as he is outside of the visibility area. At point (b) and (c), the agents is able to see the sign as it falls within his FoV. However, at point (d), although the agent is inside the visibility area, he is not able to see the sign because it does not fall inside his FoV.

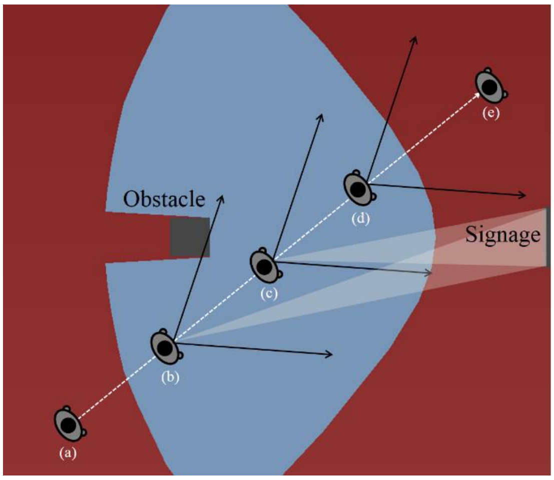


Figure 4. Visibility area and the agent's movement

4. CASE STUDY

For our verification case study, a simplified BIM model of a part of a subway station was created using Autodesk Revit. The model was then imported to the VR environment (i.e., Unity 3D) to perform computer simulation. The verification test was performed for two scenarios: (1) visualizing the visibility area and calculating signage coverage ratio (visibility area/total area of a user defined space); (2) calculating the ratio of agents that read each sign.

In our case study, in order to calculate the visible zone, maximum visibility distance (*d*) and maximum visibility angle (θ) for each sign were used. The value for *d* was set to 15 meters assuming the Japanese characters with the height of 60 millimeters based on the guideline provided in MLIT (2013), and θ was set to 90 degrees (FIP Manual, 1992). The signs were modeled at the height of 3 meters and the minimum comprehension time was set to 1.0 second. In order to calculate the view angle, the sign was represented by its center point. Hence, a cone-shaped visible zone for each sign was achieved. The heights of agents were set based on the national average for male (age 18-60), Female (ages 18-60), and wheelchair users using statistics provided in MEXT (2015). Wheelchair users' height was calculated using the average sitting height plus the average height of common wheelchairs.

4.1 Scenario 1: Visualizing the visibility area and calculating signage coverage ratio

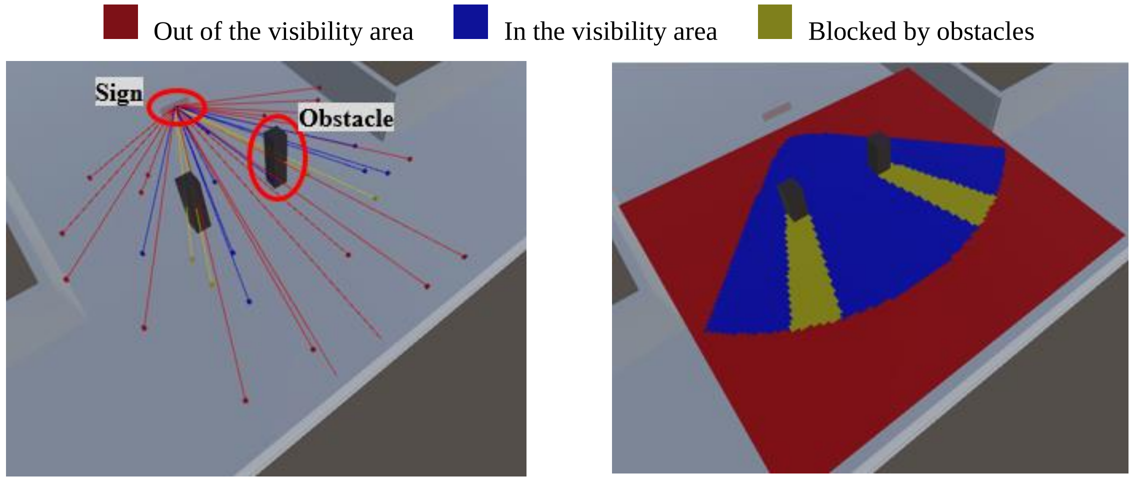
The goal of this scenario is to calculate and visualize the coverage of a sign in a defined space for different target groups of agents (pedestrians) and compare the results with alternative design options. A space with an area of $440m^2$ is shown in Figure 5(b) in red. Figure 5(a) shows different random point inside the space and shows various visibility options for those points. For example, points that are connected to the sign with red lines are out of the visibility area (either d>15m or θ>90), points that are connected with yellow lines are inside the visibility area but obstructed by obstacles (i.e. by a column), and points connected with blue lines are inside the visibility area with a clear view of the sign. Figure 5(b) shows various areas in terms of visibility (using the same color coding as lines in Figure 5(a)) for agents with the height of 1.71m (Average adult male). In the virtual reality tool, by moving the sign, these areas are automatically created to help designers with efficiently positioning the signs.

Table 1 shows the statistics that were automatically calculated by the developed tool. As shown in the table, the sign has maximum coverage ratio for male adults (31.61%). Additionally, the ratio of the visibility area for an average wheelchair user is 30.66%.

4.2 Scenario 2: Calculating the ratio of agents that read each sign

In this scenario, the movement direction, speed, and FoV of agents were taken into account. For that, the movement of passengers within the subway station was simulated. The parameters were adjusted to provide a semi-realistic virtual environment. For example, average speed of pedestrians (adult male) was set to 1.4m/s that correspond to speed of pedestrians at subway stations in rush hours. Additionally, the traffic rates for different directions and for various destinations were adjusted. Table 2 shows values of setup parameters for the test.

Figure 6(a) shows a snapshot of the simulation environment. Agents are shown with purple cylindrical shapes. Cylindrical representation of agents roughly represents the body volume and a boundary around an average person for the collision avoidance. Figure 6(b) shows the visibility status of Sign_0 for different agents at a specific instance of time. In this figure, Green lines indicate moving agents that have been exposed to the sign for more the comprehension time period (>=1sec.). The lines with blue color indicate agents that are in the visibility area but have not yet been exposed to the sign long enough to be able read the content.



(a) (b)

Figure 5. Signage visibility area visualization

Table 1. Ratio of visibility area for different groups of agents

Target Agent	Average height [m] (eye level[m])	Total area [m^2]	Visibility area [%]
Wheelchair User	1.30 (1.17)	440	30.66
Adult – Female	1.58 (1.45)	440	31.30
Adult – Male	1.71 (1.58)	440	31.61

Table 2. Simulation parameters

Parameter	Value
Sign height [m]	3
Visible distance [m]	15
Visible angle [deg.]	90
Comprehension time [sec.]	1.0

Table 3. Agents heights

Agent group	Average height [m] (eye level [m])
Adult - Male	1.71(1.58)
Adult – Female	1.58(1.45)
Adult	1.65(1.52)
Elementary school	1.37(1.24)

This scenario focuses on analyzing the visibility ratio for each sign. The visibility ratio indicates the ratio of agents that have been exposed to the sign for more than the comprehension time to the total number of agents that are target audience of the sign. In our case study, the agents who were entering the main corridor from the side corridors were target audience for the sign (Figure 6).

For this scenario two different simulations and analysis have been performed. We first analyzed the difference between the visibility ratio of the sign for adult male and adult female agents. For that, the movement of 1,600 agents has been simulated (50% male and 50% female). The goal was to identify the best design alternative. Figure 6(c) shows the setup for the test and Figure 6(d) shows the visibility status for agents at the time of the screen capture. Male agents are shown with blue cylindrical shapes and female agents are shown with purple shapes. As shown in the figure, there are five design alternatives. Table 4 (Scenario 1) shows the results of a sample simulation. Results shows that position of Sign_D is the best design alternative (with 83.13% visibility ratio). It also shows that male agents have better visibility due to their higher average height. However, the difference is relatively small (0.8% on average).

The second simulation targeted analyzing the visibility for elementary school children. For that, the movement of 1,600 agents has been simulated (75% adults and 25% children). Figure 6 (e and f) shows the setup for a simulation and a snapshot of agents visibility status. The average heights for adults and children are presented in Table 3. Table 4 (Scenario 2) shows the results of a sample simulation. It shows that the position of Sign_D is still the best design alternative. However, the ratio of agents who perceived the sign is lower for children comparing with adults.

By designing similar scenarios, the designer can analyze the visibility of signage in various locations and can choose the best alternative. Additionally, signs with the same content can be grouped and the total visibility for different groups can be analyzed. Moreover, designers can focus on increasing the visibility for specific target groups (such as children or people with special needs).

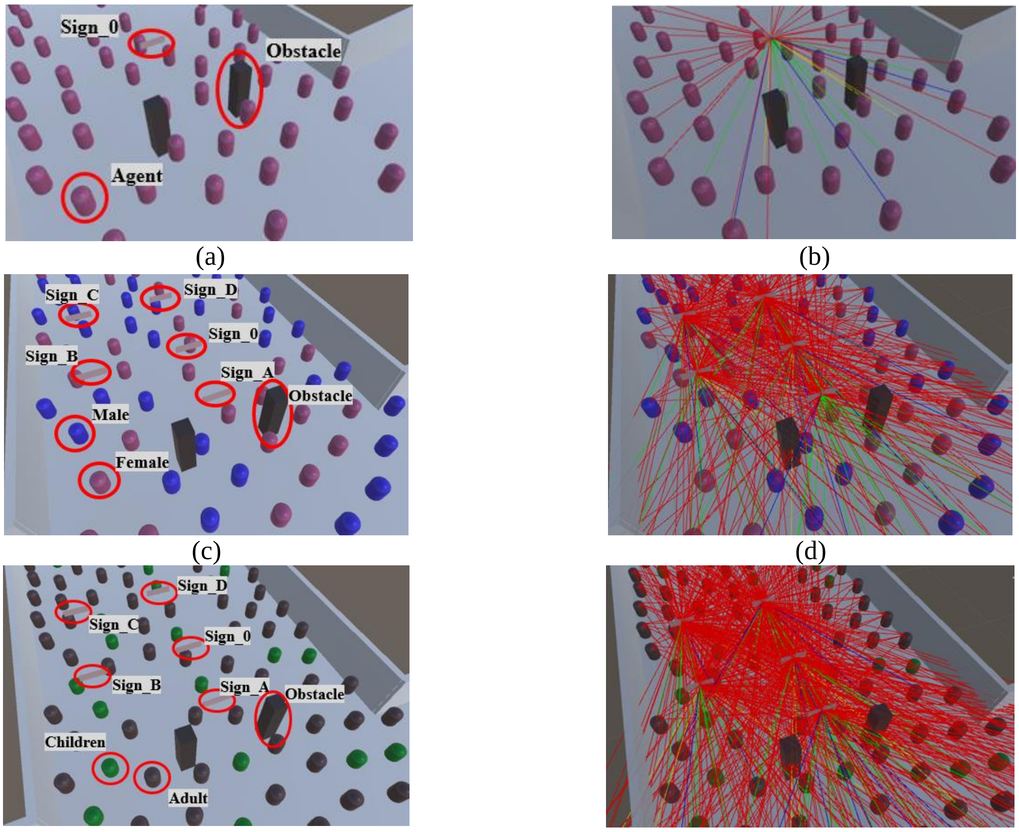


Figure 6. Agent movement simulation

Table 4. Visibility ratio for two simulation scenarios

	Scenario 1 - Male vs. Female		Scenario 2 - Adults vs. Children	
Sign No.	Male [%]	Female [%]	Adults [%]	Children [%]
Sign_0	81.37	80.25	78.92	73.50
Sign_A	58.38	57.50	53.17	50.00
Sign_B	60.88	60.38	60.33	59.00
Sign_C	62.25	61.75	61.75	61.00
Sign_D	83.13	82.13	80.67	77.50

5. DISCUSSION

The results of the case study showed that the developed tool is capable of providing required statistics and visualizations. Additionally, it provided the operator with walkthrough capability to simulate the movement of a pedestrian in the virtual environment. However, the tool can provide more accurate results if more parameters for signs and agents are defined. For example, the developed VR environment is limited to static value definitions for the height of pedestrians and their average speed.

The results can be further improved if the values for such parameters (such as height, speed and boundary dimensions) are defined using realistic probability distributions. Additionally, the simulation environment should be further completed by feeding data gathered in more thorough field observations. For verification, more complicated physical environments, movement patterns, and pedestrian traffic patterns are required to be modelled. Regarding the movement of the agents, the game engine currently uses the shortest path algorithm with collision avoidance for defined paths. However, this does not provide the most realistic behavior for agents' movement. Also, our simulation does not take into the account the head rotation, different ranges of human FoV, and issues related to eye fixation and visual attention stimulant. We considered that the FoV of 120 degrees is being equally processed by the agents.

6. CONCLUSIONS

This paper investigated a method that integrates BIM and VR environment to analyze the visibility of a signage system. Based on the proposed method, a prototype software tool has been developed and tested. The developed tool can adopt various techniques to calculate the visibility area. Additionally, values for many parameters related to signs and agents can be defined. The developed tool also simulates the movement of pedestrians within spaces using semi-realistic scenarios and generates outputs. It helps designers and facility operators implementing more effective signage system for the facility.

The tool can be further completed by considering the relationship between contents of signs and analyzing the continuity of the signage system. Additionally, the effect of different traffic rates on the agents' boundary should be analyzed and implemented. Furthermore, adding a design aid module to help designers finding the most suitable places for various types of signage (such as information, direction, or advertisement) considering minimum visual clutter and maximum visibility is a future work of this research. The authors are also planning to validate the developed method by experiments in actual subway station in Osaka, Japan. For that, realistic values for parameters of the simulation environment will be identified through extensive field observations.

REFERENCES

Albahri, A.H., and Hammad, A. (2015). Coverage evaluation of surveillance cameras using BIM and game engine. Proceedings of International Conference on Civil and Building Engineering Informatics (ICCBEI 2015), 108, Tokyo, Japan, 2015.

Becker-Asano, C., Ruzzoli, F., Hölscher, C., and Nebel, B. (2014). A Multi-agent System based on Unity 4 for Virtual Perception and Wayfinding. Transportation Research Procedia 2, 452–455.

Buechner, S.J., Wiener, J., and Hölscher, C. (2012). Methodological Triangulation to Assess Sign Placement, Proceedings of the Symposium on Eye Tracking Research and Applications, ETRA 2012, New York, USA, pp. 185–188.

Cubukcu, E. (2003). Investigating wayfinding using virtual environments, Ohio State University, Columbus.

Filippidis, L., Galea, E.R., Gwynne, S., and Lawrence, P.J. (2006). Representing the Influence of Signage on Evacuation Behavior within an Evacuation Model, Fire Protection Engineering 16, 37–73.

FIP Manual (1992). Signage: System overview and implementation. Retrieved from Federal Identity Program Manual (FIP Manual), Treasury board of Canada, website: http://www.tbs-sct.gc.ca/hgw-cgf/oversight-surveillance/communications/fip-pcim/man/man05-eng.asp, accessed on December 15, 2015.

Furubayashi S., Yabuki N., and Fukuda T. (2013). A data model for checking directional signage at railway stations, Proceedings of the First International Conference on Civil and Building Engineering Informatics, Tokyo, Japan, pp.323-330.

Hinterecker, T., Röser, F., Strickrodt, M., and Hamburger, K. (2014). SQUARELAND 2.0: A flexible and realistic virtual environment for investigating cognitive processes in human wayfinding, The Annual Meeting of the Cognitive Science Society, Presenting at the COGSI2014, pp. 2363 – 2368.

MEXT (2015). Physical fitness survey. Retrieved from Ministry of Education, Culture, Sports, Science and Technology (MEXT) website: http://www.e-stat.go.jp/SG1/estat/NewList.do?tid=000001016672, accessed on December 15, 2015.

MLIT (2013). Guidelines of public transport. Retrieved from Ministry of Land, Infrastructure, Transport and Tourism (MLIT) website: http://www.mlit.go.jp/common/001016331.pdf, accessed on December 15, 2015.

Morganti, F., Carassa, A., and Geminiani, G. (2007). Planning optimal paths: A simple assessment of survey spatial knowledge in virtual environments, Computers in Human Behavior 23, 1982–1996.

Motamedi, A., and Hammad, A. (2009). Lifecycle management of facilities components using radio frequency identification and building information model, Information Technology in Construction 14, 238–262.

Raubal, M. (2001). Agent-based simulation of human wayfinding: A perceptual model for unfamiliar buildings, Viena University of Technology, Viena.

Tseng Y., Kang S., and Moh R. (2013). BIM application on the signage system of public building at design Stage, Proceedings of the First International Conference on Civil and Building Engineering Informatics, Tokyo, Japan, pp.315-321.

USSC (2015). On-Premise Signs Guideline Standards. Retrieved from United States Sign Council Foundation (USSC) website: http://www.usscfoundation.org/USSCGuidelineStandards.pdf, accessed on December 15, 2015.

Vilar, E., Rebelo, F., and Noriega, P. (2014). Indoor Human Wayfinding Performance Using Vertical and Horizontal Signage in Virtual Reality, Human Factors and Ergonomics in Manufacturing & Service Industries 24, 601–615.

Xie, H., Filippidis, L., Galea, E.R., Gwynne, S., BlackShields, D., and Lawrence, P.J. (2007). Experimental Study and Theoretical Analysis of Signage Legibility Distances as a Function of Observation Angle, Pedestrian and Evacuation Dynamics 2005, Springer Berlin Heidelberg, pp. 131–143.