LEARNING, PROTOTYPING AND ADAPTING

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LEARNING, PROTOTYPING AND ADAPTING
VOLUME 1

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FROM AGENT TO AVATAR

Integrate Avatar and Agent Simulation in the Virtual Reality for Wayfinding

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Abstract. This paper describes a study of using immersive virtual reality (VR) technology to analyze user behavior related to wayfinding, and the integration of the technology with the multi-agent simulation and space syntax. Starting with a discussion on the problems of current agent-based simulation (ABS) and space syntax in constructing the micro-level interactions for wayfinding, the author focuses on how the cognitive behavior and spatial knowledge can be achieved with a player controlled avatar in response to other computer controlled agents in a virtual building. This approach starts with defining the proposed Avatar Agent VR system (AAVR), which is used for capturing a player's movement in real time and form the spatial data, then visualizing the data with various representation methods. Combined with space syntax and ABS, AAVR is used to examine various players' wayfinding behaviors related to gender, spatial recognition, and spatial features such as light, sound, material, and other architectural elements.

Keywords. Virtual Reality; wayfinding simulation; agent; avatar; multi-agent simulation; space syntax.

1. Introduction

1.1. WAYFINDING SIMULATION WITH AGENT-BASED MODELING

Wayfinding refers to the ability of people and animals in orienting themselves in a space and navigate from place to place. The related studies investigate different aspects of wayfinding such as route decision making, route monitoring, and destination recognition. In architecture specifically, the wayfinding studies tend to focus on the user experience and signage (and graphic communication) studies. Kevin Lynch described it as "a consistent use and organization of definite sensory cues from the external environment." (Lynch, 1960) In the context of architectural design, the term "way showing" is used to refer to the architectonics that is designed in a way to facilitate and assist navigation. Romedi Passini emphasized wayfinding from architectural design perspectives such as spatial, orientation, perception factors, and stimuli - graphic, verbal, auditory, and tactile in the book "Wayfinding: People, Signs, and Architecture" (Passini. 1992).

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There are many computational wayfinding methods to simulate agents involving movement, including ”The simple statistical regression, spatial interaction theory, accessibility approach, space syntax approach and fluid-flow analysis” (Batty, 2007). These bottom-up agents based simulation (ABS) systems can simulate real human’s movement and decision-making process. Computer models have been developed to examine the generation of agents, their spatial properties, and their interactions with the environment. Michael Batty described the property of ”Autonomy” and ”The embedding of the agent into the environment” as the two fundamental properties of agents in an ABS. An ABS consists of numerous agents, which follow localized rules to interact with a simulated environment, thereby formulating a complex system. Since Craig Reynolds’ artificial ”bodies” and flock simulation, the concept of ABS has been widely used to study decentralized systems including the crowd simulation and social interaction. ABS focuses on the agent’s properties and processes used to respond to external changes, specifically how the agents can ”sense” and ”act” to form a bottom-up wayfinding system. The actions are usually based on simple rules such as separation, alignment, and cohesion. Usually, a computer algorithm is used to control agent’s velocity, maximum force, the range of vision and other properties. For example, Po-Han Chen’s fast flow control algorithm can calculate evacuation paths in accordance with a floor plan and the total number of evacuees. (Po-Han Chen. 2009) The movement analysis is based on the minimum overall evacuation time and an optimal number of evacuees assigned to each evacuation path. However, the wayfinding simulation can also be achieved without using ABS. For instance, in Ming-Yuan Chen’s BIM-based intelligent fire reduction integrated system, the shortest safe path is determined by multiplying penalty factor from the relative paths of on fire nodes to evade the fire areas through Building Information Model (BIM). (Min-Yuan Cheng. 2016)

1.2. WAYFINDING SIMULATION WITH VIRTUAL REALITY

With the recent development of head-mounted display (HMD) such as Oculus Rift, HTC Vive, Microsoft HoloLens, and powerful mobile phones, both Virtual Reality (VR) and Augmented Reality (AR) are being reintroduced as simulation instruments into the architecture design industry. Through sensory perception and the motor response of users, VR helps a person to perform a sensorimotor and cognitive activity in an artificial world. Users can virtually change time, place and action in the virtual environment. Through supporting the perception-decision-action loop, VR allows researchers to test peoples’ Virtual Behavioral Primitives (observing, navigating and manipulating) in an immersive environment. By integrating with BIM and building emergency management protocol, VR-based simulation provided a closer result to the physical reality for wayfinding analysis and egress training. For example Bing Wang’s research on how to use BIM and VR to create timely two-way information updating convenient and simple way to increase evacuation awareness. (Bing Wang. 2014).

2. Constraints of current wayfinding methods

In the preliminary research, we have studied several computational methods for the wayfinding study, specifically focused on the multi-agent system, space syntax, and VR-based simulation.

2.1. PROBLEMS OF MULTI-AGENT SYSTEM FOR WAYFINDING

A multi-agent system is established in the same relational model and computational strategy from the early sociologists‘ research. Some of the methods involve utilizing ABS to generate micro level self-organizing movement patterns that respond to the top-down rules such as egress code. Multi-agent system allows a complex behavior pattern to emerge from a simple interaction among agents. The agent can “sense” their neighbors and “react” to them by modifying their location, velocity, orientation or other attributes. This multi-agent approach can be found in the self-organizing behavior research by Kokkugia. It also inspired Jeff Jones’ unconventional computing using the slime mold Physarum polycephalum to construct the natural multi-agent computational model. (Jones 2014) All of these wayfinding methods modeled the interaction of agents, despite model the macrostructure directly. Researchers can understand the dynamics of agents better not by modeling them at the global level but instead simulating the local interactions among these components and automatically construct the global patterns at the relational level.

The multi-agent system has been widely used to simulate the behavior of crowds, where the agents’ movements are computed based on the interactions among themselves, as well as the interactions with the environment. We designed an agent system and created the ”cognitive agents” with A.I in the Unity game engine. The agents populated a defined space and navigated through a complex 3D landscape. Different from the ”reactive” agent in the space syntax discussed later, these ”cognitive agents” had their pre-programmed decision-making tree to decide their path in a changing environment actively. These algorithm controlled agents made various decisions while evaluating the changing context in real time.

Figure 1. Multi-agent simulation in the 4400 lecture hall, DAAP building. Unity game engine. By Laura Kennedy. .

In the evaluation stage, spatial explorations concepts of the multi-agent system allowed us to compare the decision makings and behaviors of a digital agent with a real human during an egress. We soon realized the difference between these two and acknowledged the distinction between a computer-simulated agent and a real human regarding the wayfinding behavior. Although multi-agent system calculated an agent’s changing state through time, based on the state of neighboring agents and context, it did not necessarily represent the complex, and sometimes irrational human behavior in the real world such as following the crowd and panic during the egress.

2.2. PROBLEMS OF SPACE SYNTAX FOR WAYFINDING

Space syntax is another method to study the movement pattern and accessibility of a network based on the lines, nodes, and connections. It is widely used in the vast urban scale to study connectivity of the street network. With its own "agent analysis" tool, space syntax does not simulate the interactions among agents. However, space syntax provides fast feedback between geometric elements and computes their accessibility values within an environment defined by a grid of cells. Through importing a building floor plan into space syntax analysis tool, we produced a heat map to represent accessibility and spatial integration. The warmer color represents higher spatial integration values. We computed the integration value of each cell by the analysis tools in space syntax and visualized the values with colors. The quantitative values extracted from the space syntax analysis were imported into Grasshopper for further computing. To convert the space syntax result into a heat map representation, we created a data processing method to expand the color values automatically from paths to zones. These zones were used later to plan where to "spawn" the agents. However, it became evident that the interactions among agents, the complex social behavior could not be simulated through the space syntax alone, although it provided a fast way to visualize interactions between the agents and the environment.

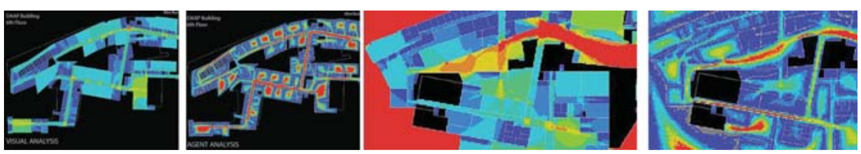


Figure 2. Space syntax agent analysis. DAAP building.

2.3. OUR APPROACH: AVATAR AGENT VR SYSTEM (AAVR)

As two simulated bottom-up systems, both multi-agent system and the space syntax computed the changing status of an agent over time. However, as discussed before, we discovered that the agent behaviors of these two methods were often unrealistic and lacked purposive planning goals. These methods merely relied on the external rules to influence the agents' behaviors and dictate their movement. Finally, we designed a new method by integrating ABS and Space syntax with immersive VR through a player controlled avatar. Like in a video game, a player is graphically represented in the virtual world as an avatar. Surrounded by the crowd of agents who were automatically generated by the computer, the avatar's movement was fully controlled by the player. While the agent's "spawn" position was based on the space syntax heat map, its movement was fully controlled by the computer simulation. This hybrid "avatar + agent VR system" (AAVR) allowed us to examine the complexity of human cognitive pattern responding to the predefined rules and other ”purposive goals” beyond context awareness. In this new method, an avatar with its human master had the full decision-making ability to respond to the context and modified its complex behavioral parameters and interacted with the computer controlled agents. AAVR allowed us to take advantage of the autonomous, bottom-up ABS approach and integrated various agent related computations into VR.

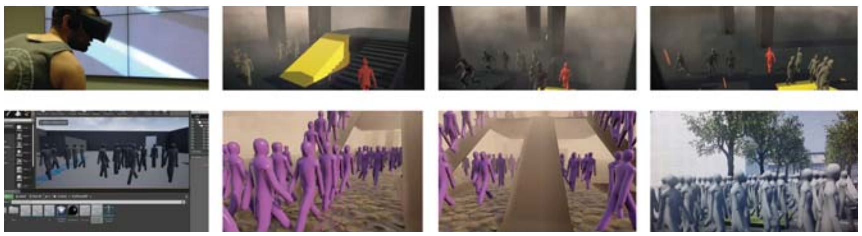


Figure 3. Top: third person view in VR with player controlled avatar (red color character) and A.I controlled active agents (gray color characters). Bottom: First person view in Unreal and Unity game engine with a large crowd (purple color characters) imported from external ABS. By Ming Tang, Joe Gruzinsky.

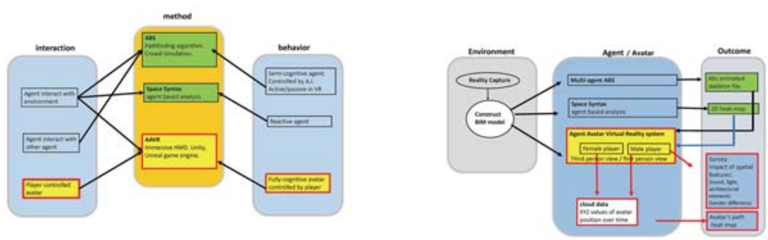


Figure 4. Left: Three methods: space syntax, ABS, AAVR. Right: Workflow of AAVR system.

3. Implementations of AAVR for wayfinding

In 2017, we applied AAVR method to examine the wayfinding using the College of Design, Architecture, Art, and Planning (DAAP) building at the University of Cincinnati. The DAAP building, also named as Aronoff Center for Design and Art, is a 164,000-square-foot addition, which opened in 1996 and linked together the previously existing Alms, DAAP and Wolfson buildings at the University of Cincinnati. Designed by renowned architect Peter Eisenman, the DAAP building has generated much national and international critical attention. Famous for its “deconstructionism” style, the building contains a complex circulation system, with many classrooms, public gathering places, critic spaces, and service areas. Wayfinding is always a big challenge for the first-time visitors, even for the students who have used the building for years.

To start the simulation, we first created a Building Information Model to represent this eight-story building. We then scanned several interior spaces with a laser scanner, and constructed an accurate interior space based on the scanned point cloud in Autodesk Recap. We transferred the 3D building model into the Unity game. Every single room, hallway, and stairs were carefully modeled based on the actual dimensions. We added the material and lighting. Fire and smoke were also added in several places. Use DAAP model as a virtual environment, we applied AAVR wayfinding analysis method. Physics-Based sunlight and artificial lights were baked into a global illumination light-map. Spatial sounds and fire alarms were also added to the VR system. (Figure 5) An Oculus Rift HMD was used to allow the users to experience all these spatial features.

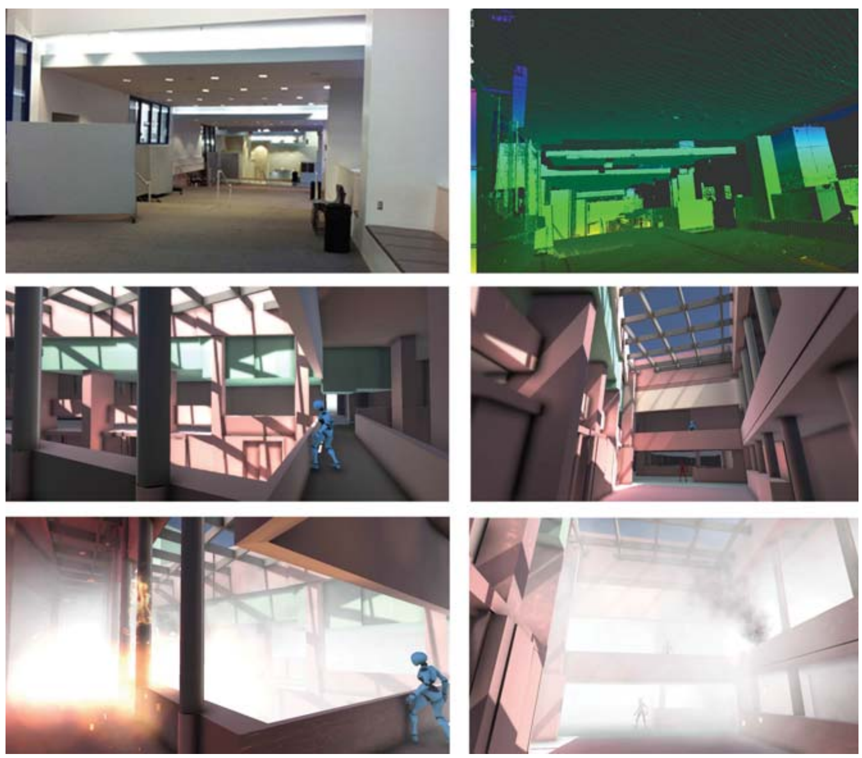


Figure 5. DAAP building. Top. Reality Capture with a laser scanner and Autodesk Recap. Middle: the virtual DAAP building in the Unity game engine. Bottom: smoke and fire simulation in VR.

Instead of programming agent's behavior through computer scripts, we recruited people to control an active avatar in AAVR. Observed by the player through third person view (or called shoulder view), the avatar was controlled by the player with a game controller, a keyboard, and a mouse. The avatar interacted with the virtual DAAP building populated with other computer controlled agents. Through the built-in character control system in the Unity game engine, we optimized the avatar's movement and running speed to match the real world physics.

Besides the player-controlled avatar, there were two groups of agents in AAVR to form the crowd. One group of agents, usually contain 200 agents or more, was precomputed in an external crowd simulation program outside of Unity. The spawn location of these agents in the virtual DAAP building was based on the previous space syntax analysis. Agents' movement were baked into a series of skeleton keyframes and imported into the Unity engine to assemble the crowd. We named this group as ”passive agents” since their simulation was baked into keyframes and would not have real-time interaction with the avatars and changing environment. The second group of agents, usually 50 agents or less, was also spawned in the zone indicated by the space syntax analysis. However, they were controlled by the A.I in the Unity game engine. They can actively interact with an avatar such as following, keeping distance, or running away. We named this group of agents as ”active agents.” These two groups of agents created a dynamic crowd scenario in the AAVR simulation.

At the beginning of the test, the researchers explained the wayfinding task to the participants. The participants were told that they were in a building which is on fire, and they have to exit the building as soon as possible. A participant should use all visual, audio cues, as well as their sense of spatial organization to find their way out.

During the test, the participant's avatar spawned in a zone full of smoke. The visible fire could be observed in the distance. Fire alarms could be heard and got louder when the avatar walked closer to the alarms. The challenge for a participant is to control an avatar to get out from one of the six exits in the building. Once the avatar reaches an exit, the task is complete. The avatar's movement and travel time were automatically recorded into series of values and stored in an external dataset.

After the test, we extracted participants' movement XYZ values and time values captured in the dataset. We then reconstructed the data as a series of travel points and curves in Grasshopper and Rhino. These travel points were assigned colors based on their proximity to other points. A heat-map was automatically formed to represent the spatial congregation. After the participants completed their tasks and took off the HMD, they were asked to fill out a questionnaire. Example questions were, to what extent the sounds assist participants in their navigation? To what extent the light assists participates in their navigation?

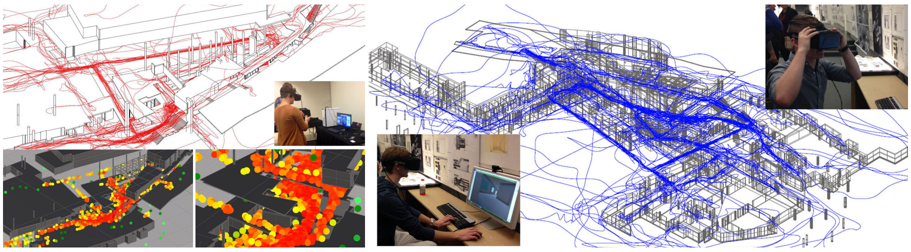


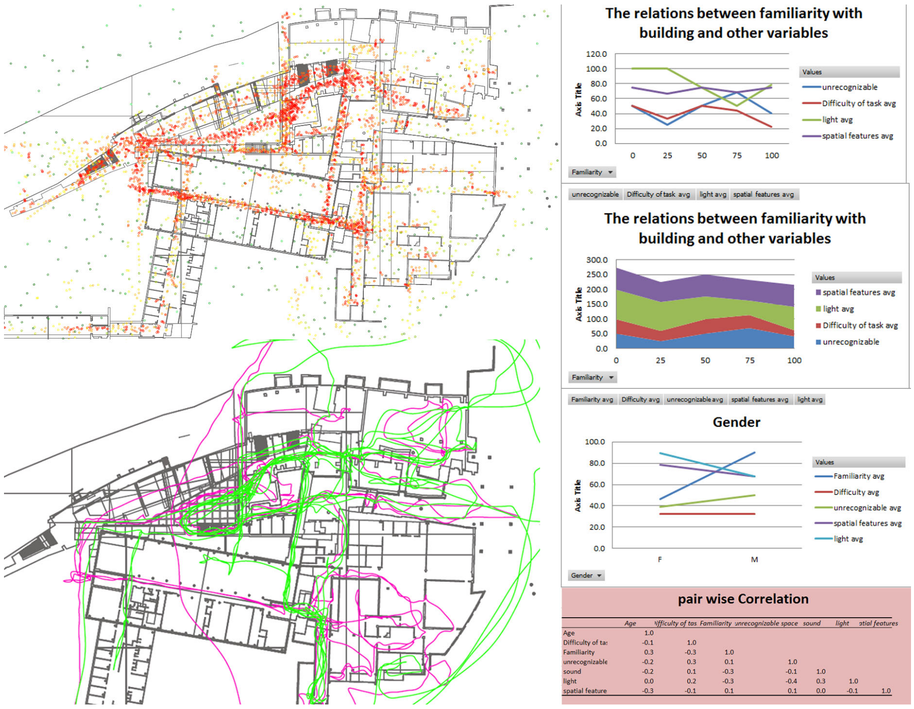
Figure 6. The researchers applied AAVR simulation to record how players navigated in the virtual DAAP building and generated path graph. The Unity game engine was used as a virtual playground to establish a series of tasks and a data capturing environment.

4. Evaluation of AAVR for wayfinding

The AAVR wayfinding study lasted three weeks. It focused on the group of people who were already familiar with the building and evaluated their wayfinding behavior in the presence of fire and dense smoke. Thirty undergraduate and graduate students were recruited and participated the test and survey. The number of male and female participants were nearly equal. Participants spent average 3-4 minutes reading the description of the task, signing the consent form, adjusting the HMD before they started the test. Then participants spent around 10 - 15 minutes completing two tasks. Task-A is to exit the virtual DAAP building during the emergency evacuation. Task-B is to walk through the same building in the usual situation. Virtual fire, smoke and alarm sound were only added in the task-A. Participate spent 5 minutes filling a questionnaire after the two tasks.

In task-B, the casual walk scenario, we found the agents' aggregation has a very similar pattern matching the result from the previous space syntax and multi-agent method. The central atrium with skylight attracted more circulation and became a public gathering place. In task-A egress scenario, the same atrium became the most recognizable space to assist the wayfinding in the smoke condition. The visible daylight, material, and louder alarm sound made this space distinct from the rest of DAAP building.

We also found AAVR wayfinding result is different from the previous two methods. For instance, the grand stairs in DAAP, which is a very long linear space adjacent to the central atrium with a relatively low ceiling and dimmed daylight, attracted many agents in the space syntax and multi-agent simulation. However, it did not attract many avatars in the AAVR simulation in task-A and task-B. This might be due to the "less intelligent" agents in the first two methods lacking the understanding of complex spatial features such as the elevation change, height-depth proportion, space usage, and illumination level.



	Age	ifficulty of tas	Familiarity	unrecognizable space	sound	light	atial features
Age	1.0						
Difficulty of ta:	-0.1	1.0					
Familiarity	0.3	-0.3	1.0				
unrecognizable	-0.2	0.3	0.1	1.0			
sound	-0.2	0.1	-0.3	-0.1	1.0		
light	0.0	0.2	-0.3	-0.4	0.3	1.0	
spatial feature	-0.3	-0.1	0.1	0.1	0.0	-0.1	1.0

Figure 7. Data analysis based on avatars' movements. Top left: heat-map to represent congregation value. Bottom left: paths by gender. Green color: male. Purple color: female.

From the heat-map and paths generated from male and female participants in the AAVR method, we did not find a significant gender difference in the wayfinding behavior. Although a few male and female participants failed to find an exit and end the task early, both genders had a similar reaction to the spatial features such as sound, material, and light based on the survey data.

5. CONCLUSION

Wayfinding simulation helps us to evaluate an architectural space and improve efficiency, accessibility, and safety of the built environment. Good design space and wayfinding system can help people to decrease frustration, stress, anxiety caused by getting lost. Our research investigated multi-agent simulation, space syntax, and VR simulation. In the first two computation methods, the simulation was a result of the interaction between agents and their environment and the modulation of agents' behaviors within external rules. Comparing with the first two methods, the avatar-based wayfinding provided a closer result to the reality. It relies on the real human players and their wayfinding rationales. Together with survey and questionnaire, both quantitative and qualitative feedback was collected. As a result, the new AAVR approach produced measurable improvement in the wayfinding simulation.

However, this AAVR method has a few limitations. Realizing the crowds were computer generated props, the participants often ignored these agents and only evaluated the environment to facilitate wayfinding decisions without the influence of the crowds. Lacking the avatar to agent interaction, avatar's behavior was isolated from the influence of the crowds in the egress scenario. In our next phase investigation, the AAVR-based analysis would be able to allow multiple participants to experience a shared space like a mass multi-player game and influence each other. We are currently designing a multiuser interface of AAVR to integrate remote players as avatars into a shared VR. We are also working on capturing eye-tracking data of a player in the VR environment. The goal is to exam the gaze pattern and fixation duration allowing researchers to study the human perception and attention to various spatial features related to the wayfinding.

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References

Aschwanden, G.: 2012, Agent-Based Social Pedestrian Simulation for the Validation of Urban Planning Recommendations, *sigradi 2012*.

Batty, M.: 2007, *Cities and Complexity, Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals.*, MIT Press.

Chen, P. and Feng, F.: 2009, A fast flow control algorithm for real-time emergency evacuation in large indoor areas, *Fire Safety Journal*, **April 2009**, 732-740.

Cheng, M., Chiub, K., Hsiehc, Y., Yangd, I. and Chou, J.: 2016, Development of BIM-based Real-time Evacuation and Rescue System for Complex Buildings, *Proceedings of 33rd International Symposium on Automation and Robotics in Construction (ISARC 2016)*.

Kevin, L.: 1960, *The Image of The City*, MIT press.

Romedi, P.: 1992, *Wayfinding: People, Signs, and architecture*, Mcgraw-Hill.

Wang, B., Li, H., Rezgui, Y., Bradley, A. and Ong, H.: 2014, BIM Based Virtual Environment for Fire Emergency Evacuation., *The Scientific World Journal*, **Volume 2014**, 22.