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WHERE AM I?

Spatial Cognition Inside Building Information Models

ANTONY PELOSI
[1] *Victoira University of Wellington, New Zealand*
[1] *antony.pelosi@vuw.ac.nz*

Abstract. How do we know what we are looking at while viewing inside Building Information Modelling (BIM) models? Current architectural software typically provides disconnected methods of aiding spatial cognition. There is a strong history of navigation tools developed for controlling our exploration and movement in BIM models, a study by Ruby Darken and John Sibert (1993) found these tools had a strong influence on people's behaviour and understanding of digital space. People perceive and navigate space differently depending on their individual experience with a BIM model, designers and architects build up a detailed cognitive map during the design of a project, while other people have a less detailed comprehension of a project, having only been exposed to select views. This paper will outline key strategies to improve how people comprehend digital space, supporting people in understanding distance and size while inside BIM models. Three design research projects will be presented. The result of the projects define three strategies; Architectural wayshowing, interior-aware transitions, and distance confirmation. Architectural wayshowing needs to be implemented during the design phase, while the remaining two need to be introduced into BIM editing and viewing software.

Keywords. Whiteout; wayshowing; spatial cognition; navigation; BIM.

1. Introduction

Building Information Modelling is employed across all stages of architectural production. While BIM provides many benefits (Eastman et al. 2011), navigating around the model is still problematic, resulting in frustration and inaccurate spatial cognition. People often become 'lost', even experienced BIM operators, inside a model (Dodiya & Alexandrov 2008; Kopper et al. 2006) causing an "unproductive and unpleasant experience, even when trying to do the most basic three-dimensional navigation operations" (Fitzmaurice et al. 2008, p. 7). These experiences of becoming 'lost' inside BIM models are similar to experiencing whiteout conditions, the loss of clues that we use to spatially orient and locate ourselves, that arctic explorers face. Explorers of BIM models become confused and frustrated when confronted with whiteout conditions.

The aim of this research is to examine methods of improving spatial cognition through aiding navigation inside BIM models. This research sets out to advance navigation of BIM models to expand people's spatial cognition in improving design, construction and building operation. Typically the design team have a resolved cognitive map of a BIM model due to their involvement in a building project, however many others involved have a incomplete or even incorrect understanding of a proposed building.

Navigation can be defined as the action of determining your position and direction allowing movement to another location. Another more useful definition, that of Professor of Computer Science Laura Leventhal, is "navigation is the cognitive process of acquiring knowledge about space, strategies for moving through space, and changing one's meta-knowledge about space." (Jul & Furnas 1997). Through the act of navigation one creates a cognitive map of space they move within. This is straightforward with viewing an object, such as orbiting around the exterior a building,. Once digitally inside a complex space, such as the interior of a building, all the clues from the external environment are lost. The standard navigation tools: orbit, pan, etc are less useful inside, even the walking tools are frustrating.

In his book The Lost Art of Finding Our Way, Professor John Huth states that "all navigational cultures have to deal with similar challenges: spatial orientation, the ability to estimate distances and find position from environmental clues" (Huth 2013, p. 8). These three challenges are still the case inside BIM models, while research has provided solutions for aiding spatial orientation and location identification (Chittaro & Venkataraman 2006; Dodiya & Alexandrov 2008; Ruddle et al. 1997) There has been very little research of or support for helping people understand distance inside BIM models (Interrante et al. 2006; Leyrer et al. 2015; Ries et al. 2008; Turner & Turner 1997), these papers highlight that people underestimate distances inside digital space, they do not offer any methods of supporting or aiding people in helping to estimate distance with more accuracy to improve spatial cognition.

To move within BIM models, where moments of whiteout are common, we need to navigate the unknown. John Huth's (2013) three elements of navigation give clues to aid experiencing BIM models. I believe that spatial orientation (Fitzmaurice et al. 2008; Ziemek et al. 2012) and location awareness (Luo et al. 2010) have adequate solutions already, although whether they are being utilised is beyond the scope of the present research. In contrast, the estimation of distance inside BIM models is poorly supported, which suggests that aiding distance cognition will improve navigation and reduce moments of whiteout.

When viewing a BIM model, predefined views have commonly been created, based either on major drawing projections such as plans, sections, elevations, and perspective views or on clashes detected and requiring resolution. Some software provides a spatial transition between the defined views, whereas others jump instantly between views. The spatial transition helps orient and locate people if the correct transition is used. What is not clearly represented is the distance travelled between views. Knowing the distance between views helps in building an accurate cognitive map. These transition function by treating the model as an object, ignoring the interior layout of a building.

The term wayshowing refers to the activity of planning and implementing orientation systems in buildings and outdoor areas, this often incorrectly described as 'wayfinding' (Mollerup 2013). People have always practiced wayshowing by leaving clues, marks, or signs. Wayshowing and wayfinding relate to each other like cooking and eating. Wayshowing proceeds and enables wayfinding. "Wayfinding is what we do when finding our way around unknown quarters. Good wayshowing is user-led, built on how we practice wayfinding" (Mollerup 2013, p. 6).

As digital workflows encompass virtually all stages of architectural production knowing what and where you are inside digital models becomes critical. The paper will outline three key strategies that help reduce moments of whiteout and improve spatial cognition.

2. Method

The research covered in this paper is positioned as research by design practice, a reflection-in-practice process of designing via making, based on what Donald Schön considers designing as a reflective conversation with the material of a situation (1983). Practice as creative-making activity is an "explicit and intentional method for specific research purposes" (Gray & Malins 2004, p. 104) through design and reflection. The process of reflection is embedded within the projects, which were evaluated during the designing, making, and testing, thereby informing the next project.

Exploration of possible research instruments exposed the limitations of those used by Doug Bowman et al. (Bowman et al. 1998), including that a memory task for information gathering within an immersive virtual environment may not give a clear response of the navigation modes. Sketching cognitive maps was rejected because a cognitive map is constructed of multiple sensual inputs that are impossible to capture in a sketch-which typically defaults to a plan and can be limited by people's perceived drawing ability. Spatial cognition is manifest in an individual mental image or cognitive map and requires all of our senses, it is not completely understood (Montello 2001; Tversky et al. 1999; Waller & Nadel 2012).

Different research instruments (Wilkinson & Birmingham 2003) are used across the projects, they are case studies that employ observation, a questionnaire, and critical reflective research methods. Using a questionnaire in the Te Ara Hihiko project provided qualitative responses to wayfinding tasks, asking people to rate spatial awareness with different navigation support provided while searching for different locations within a BIM model. Te Ara Hihiko project used the work of Bowman, D. A. et al. (1998) paper A Methodology for the Evaluation of Travel Techniques for Immersive Virtual Environments, allowing a range of criteria across different conditions to be evaluated.

The concept of whiteout is the base criterion used in evaluating the project work: how does each project improve spatial cognition and reduce the incidences of whiteout inside BIM models? To understand a building spatially, we need to experience moving inside the structure. Whiteout moments are the times you become stuck while experiencing the model, the information you want is obscured, often resulting in frustration and misunderstanding of the model.

3. Projects

The projects provide explorations of assistive interfaces for spatial cognition and awareness that aid in the estimation of distance within BIM models. Previous research has focused on unaided experiments in virtual environments of distance estimation (Interrante et al. 2006; Ries et al. 2008; Turner & Turner 1997). The projects in the present research explore methods of assisting people to improve distance and scale awareness, each project investigates methods of aiding distance awareness: Te Ara Hihiko critiques the mouse walk tool by providing different levels of guidance; Odograph records and displays total and last distance travelled, aiding in the spatial comprehension of a building; Your Grid develops a spatially aware personal grid that is overlain at current floor level, aiding distance estimation. All three projects interrogate methods of aiding spatial cognition via improving distance comprehension. Each project tests the implications of different modes of understanding distance.

3.1. TE ARA HIHIKO

Te Ara Hihiko is māori and translates as The Creativity Path, this project investigates the functionality of the mouse walk tool against different levels of guided navigation. This was done by tracking the orientation and wayfinding of 12 participants exploring a three-dimensional BIM model given three tasks. A call was made to a local Revit users group for participants, allowing for experienced users, use to working in complex BIM models .The following performance metrics: Ease of Use, Spatial Awareness, and Information Gathering were selected from Professor Bowman and co-workers paper entitled ‘A Methodology for Evaluation of Travel Techniques for Immersive Virtual Environments’ (1998) to help explore the question of how spatial orientation and an understanding of location can be improved in BIM models.

The project explores three travel techniques, Mouse to Walk with recommend AI interior-aware path to follow and automated interior-aware AI generated transition. The former technique responded to the current standard CAD/BIM software mouse command of click and drag to ‘walk’. People were limited to this method of movement in order to explore how they use this often-under-utilised tool. A ‘look’ command was also provided. The second techique, free-form travel was supplemented with a guided or recommended dynamically created AI path. The third travel technique was a fully automated AI directed path that takes the participant on a completely guided walk or interior-aware transition to the specified location.

The guided AI system leveraged the Unity AI pathfinding technique that dynamically generates a line showing the shortest walkable path to the target room's location. An invisible controller is spawned at the participant's location; the invisible controller then travels to the target location at walking speed, leaving a coloured graphical line showing the path. The intention is for the participants to follow this line as it travels towards the target.

The three tasks were designed to get the participants to find given locations via different navigation methods. The tasks provided movement across multiple levels and different types of spaces that most participants would not have previously entered or known of in the physical building. Task one used only standard mouse-controlled walking and looking tools, with the participants' current room and level information being given in the top-left- hand corner of the web player frame (figure 1). Task two used the same navigation tools and current location with an AI trail to follow. Task three was an AI-generated auto-walk option that guided the participant automatically to the destination. The tasks were as follows:

- Task 1: navigate to room Studio D (a large open space on Level D)
- Task 2: navigate from room Studio D to Studio B (a small studio space on level B).
- Task 3: navigate from Studio B to the studio E on Level E.

At the completion of all three tasks participants were asked to rate the following criteria:

- Ease of Use: How easy did you find navigation for task 1?
- Difficult 1 2 3 4 5 Easy
- Spatial Awareness: How well did you know your position and orientation during and after task 1?
- No idea where I am 1 2 3 4 5 Know exactly where I am
- Information Gathering: How perceptive of the building were you while moving for task 1?
- Unperceptive 1 2 3 4 5 Very perceptive.

3.2. ODOGRAPH

This project aimed to provide a clear method for measuring how far the user has travelled since their last resting place, and if the destination is predefined, to display the distance remaining to travel in real time to help build a scaled cognitive map. The concept behind providing distance information is to help draw connections across a digital model so that we can develop correct relationships between spaces and views of the model, thereby developing spatial awareness. Odograph sets out to accurately aid distance estimation while navigating inside a BIM model, displaying the total distance travelled, the last distance travelled, and indicating whether the user is moving or still (figure 1). By providing an accurate gauge of the total distance travelled, the scale represented by a model can be understood. Although a trained architect may know this intuitively, it is not always the case. People without the spatial training of an architect or builder experience models with a different understanding of spatial scale. This is similar to the way in which many people are unable to understand architectural drawings. A more immediate distance cognition is the distance a user has travelled from their last resting location, and allows a quick assessment to be made of the distance between two rooms or the length of a single space. These distances help to build a scaled cognitive map of a building model by quantifying an experience that is typically forgotten about. The interface also displays whether the user has paused long enough (or not) to trigger a new segment of measurement, indicating a break between distances.

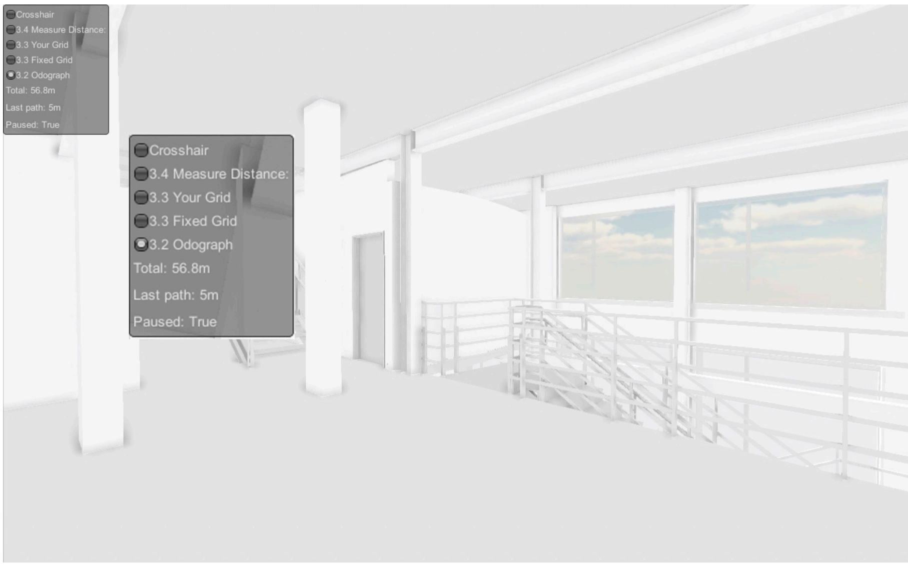


Figure 1. Odograph records and displays the user's total distance and last distance travelled, to allow correct comprehension of the scale of a building.

3.3. YOUR GRID

Grids are "one of the oldest architectural design tools" (Gross 1991, p. 33), and have been and continue to be used for designing the location of architectural elements. At some point in the late nineteenth or early twentieth centuries, a datum matrix became a convention for locating a dimensional reference system or what is commonly referred to as the column grid or building grid. This grid establishes a datum for major structural elements and can be represented in plan, section, and elevation views. The column grid is a powerful ordering device and important locating mechanism, often the key origin device in plan drawings that functions when an overview is possible. When inside a BIM model, the column grid is usually obstructed or not visible at all. Related to the (lack of) visibility of the column grid is a lack of a consistent distance between lines, due to the relationship of the column grid to the building structure. With architectural drawing sets, a clear order of view and context is constructed from plan views, elevations, and sections, down to details. The plan or section provides the overarching context, but such context can be easily lost inside a BIM model. With respect to spatial cognition, these limitations can confuse a person viewing the interior of a model. The premise of Your Grid is to provide a standard one-metre grid that is located between the viewer's position and the nearest floor level. The project seeks to provide an egocentric one-metre square grid that can be used to gain a sense of scale (figure 2). The grid is centred on the viewer to quickly give the correct size of what is currently being viewed, either an exterior view, or a tight interior view of structural elements. Your Grid can be configured to appear only while still or to follow the viewer as they navigate through space. Once stationary, users are able to adjust the grid's rotation to allow it to align with key elements.

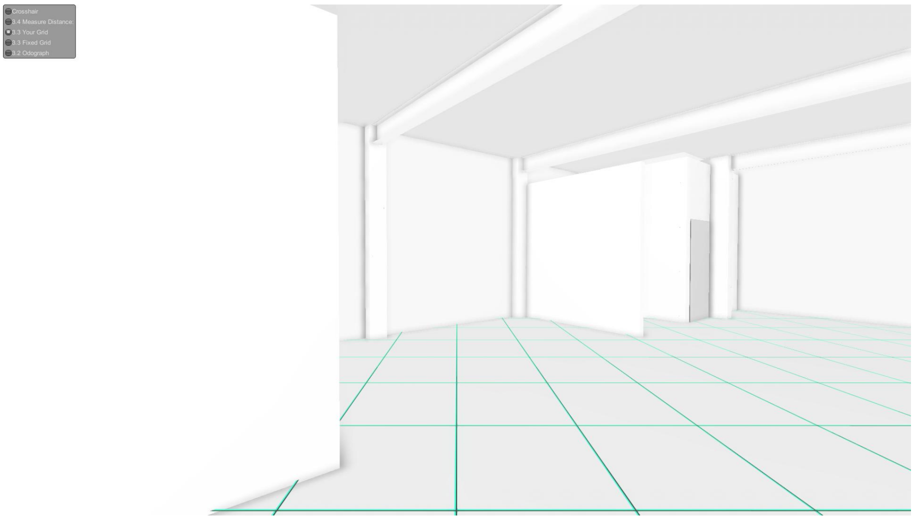


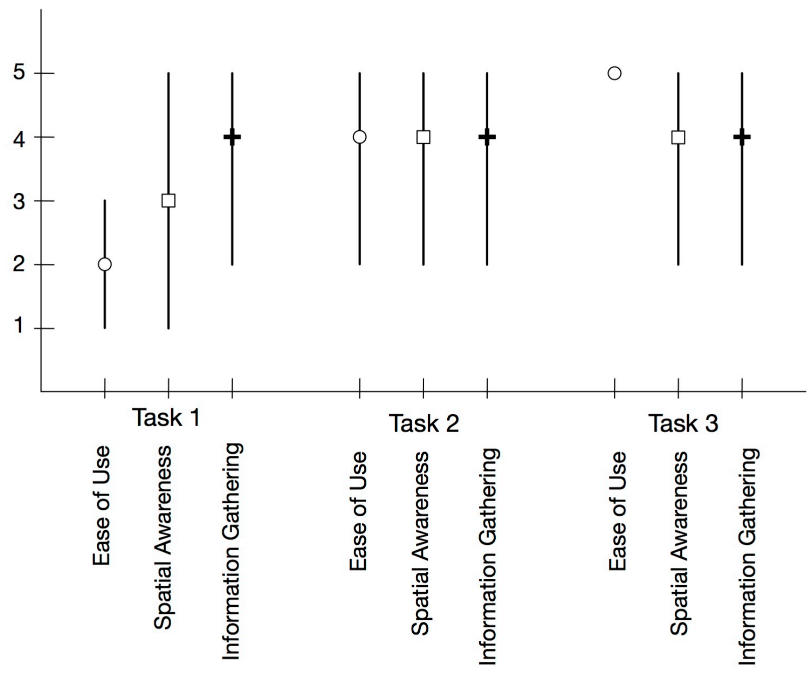
Figure 2. Your Grid locates a 1-metre grid at the nearest floor level to the user's location, which can be rotated to align with their view. The grid can be set to appear only while stationary so as to enable unobstructed navigation.

Your Grid differs from existing grids in three-dimensional software, which are oriented around the origin of the digital environment (0,0,0). Once inside a building model, these grids are obstructed, rendering them ineffective in aiding spatial cognition. Autodesk proposed a smart multiscale reference grid (Glueck et al. 2009), which also stays fixed around the origin plane, responding to the scale of what is being viewed (for example, drawing the grid at millimetre intervals when viewing a small object or at kilometre intervals when viewing a city). Your Grid is set at a constant scale, a metre grid, a building scale, which allows a viewer to quickly understand what is being viewed. When a viewer is focused on a detail, it quickly becomes clear that the view is scaled under a metre, or looking out across an open room the size can be estimated by counting the grid lines. Your Grid provides a frame of reference to understand the scale of what is being viewed. This contrasts with the observation that "typical three-dimensional software applications do not account for the scale of the environment within their navigation tools" (McCrae et al. 2009, p. 7).

4. Results

Although “there is no one proper way to navigate” (Huth 2013, p. 8), an understanding of distance helps to appreciate the complex behaviour of navigation. We all have different abilities of navigation and spatial cognition that impact on our experience inside BIM models. The navigation tools that allow us to explore inside digital environments also influence our experience. I explored the mouse walk tool by testing three levels of aiding location-finding. The aided pathways, which highlight the benefits for spatial awareness and the improved ease of use of location-aware relative distanced paths, assist people to spatially understand a BIM model. With further explorations of aiding distance estimation, the projects of Te Ara Hihiko, Odograph, and Your Grid, demonstrate enhanced methods of supporting spatial cognition within the interiors of BIM models. These projects began to establish an important area, that of aiding distance cognition within BIM models, reducing whiteout moments, each project offers a specific identification of distance, Odograph allows understanding of distances travelled benefiting comprehension of scale between rooms, Your Grid provides a spatial grid that intuitively shows the scale of a room.

Table 1. Te Ara Hihiko ease of use, spatial awareness, and information gathering range and average responses for each task.



Reflecting upon the projects resulted in the importance of how the design of a space impacts the wayshowing experience, users of a building build up a cognitive map while exploring it, considering the first person architectural wayshowing. Designers can leverage the first person view within BIM models to develop ways of architectural wayshowing to help people finding their way. Currently BIM software either moves instantly to different views or transitions with no understanding or respect of the architectural design and context. By adding spatial transitions that actively respond to floors and walls, allowing people to experience the building design, helping to build a correct cognitive map. Interior-aware transitions would help people understanding where they are and what they are looking at with in the model.

5. Conclusion

Navigating the unknown is hard. Navigating within unknown BIM models is harder. In my research, I sought new approaches to design methods of navigating BIM models to gain enhanced spatial cognition. Using a reflective practice methodology of project-based design investigations, the research explores aiding distance estimation and wayshowing methods that allow spatially aware navigation tools to reduce moments of whiteout.

The architecture and construction industries are in transition from a two-dimensional workflow to multidimensional data-driven processes. I argue the need for advanced navigation tools in this transition to improve people's' spatial cognition. Three projects investigated methods of improving spatial cognition inside BIM models, Te Ara Hihiko, Odograph, and Your Grid. Each project investigated different methods of aiding, AI pathfinding, distance traveled and a view user centric grid. The results of these projects distilled three strategies to improve spatial cognition; assistive interfaces, architectural wayshowing, and spatial transitions.

Future research needs to address virtual reality VR and augmented reality AR and how methods of navigation can help improve spatial cognition. Currently VIVE headset and controls allow people to jump to new location, this allows an intuitive method of navigation, it is still spatially confusing. John Bowman stated "that jumping techniques can reduce the user's spatial awareness" (Bowman et al. 1997, p. 51).

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