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Exploring staircases as architectural cues in virtual vertical navigation

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ABSTRACT

Architectural design requires experiencing the spatial organization of a building, discovering architectural cues and maintaining spatial orientation during navigation. Architects configure architectural cues in the initial phase of the design process. Staircases, as a feature of local architectural cues that provide access to the other floors in a multi-level building, can have an impact on vertical navigation and aid individuals during navigation and influence their spatial orientation. This study focuses on the issue of vertical navigation during virtual navigation by integrating the individual differences and the geometric attributes of a staircase pair within two different multi-level desktop virtual environments (VEs). The angle between the cue pairs with respect to the same observation point is altered in order to determine the staircase pair that is more efficient in navigation. Virtual vertical navigation is based on an egocentric frame of reference where the participants have control of their movements. Circulation paths, gender differences, navigational abilities and cue pairs are the factors that affect staircase preferences for ascending and descending. For the VE with a 180° difference between the cue pairs, a relationship was found between the ascending and descending staircases. Further analysis indicated that the staircase preference in ascending was either related to the first or last visited rooms on the ground floor. For the VE with a 90° difference between the cue pairs, no relationship was found between the ascending and descending staircases as well as with any other factor. There was only a significant relationship between gender and staircase preference in descending staircases with 180° difference between the cue pairs in favor of females. In addition, there was no significant relationship between the navigational abilities and staircase preferences.

1. Introduction

The architectural design process, as a problem-solving activity, influences the comprehension and knowledge of spatial orientation and navigation in the built environment. In order to understand a building's spatial organization and circulation system, one needs to make his/her way through the building. Hölscher et al. (2005) stated that we do not experience the spatial layout of a building as a static structure, but perceive it because of movement; we discover architectural cues systematically. Architectural cues are crucial cues configured by architects in the initial design phase of the design process. Various local architectural cues within an environment can aid individuals during navigation and influence their spatial orientation.

One of most important local architectural cue that enables vertical circulation in a multi-level building is the staircase. In architecture, the staircase functions as an important circulation node, a vertical interconnection and enables movement between the different levels of the building. Furthermore, staircases help to combine vertical information during movement and enable the individual to understand the spatial organization of the building (Hölscher et al., 2006). Since vertical circulation is one of the most important aspects of good building design, architects need to consider two key design parameters while designing the staircases. The first one is "the constructional and representational form of its appearance have to be highlighted with respect to the function of the building" and secondly, the position of the staircase has to be designed accordingly with the individual's activity within the building (Hölscher et al., 2006: 297). Besides, staircases can be problematic during vertical navigation since they can cause disorientation (Buechner, 2010; Hölscher et al., 2005; 2006; Passini, 1984).

The spatial configuration of the built environment influences the behavior and decisions made while people are navigating in space (Natapov et al., 2015). With the aid of virtual environments (VEs), architectural cues could be designed with varying configurations according to the needs of its users. This study aims to provide an understanding on how local architectural cues, especially staircases with respect to their geometric attributes, are utilized during vertical navigation and how they influence the individual's vertical navigation behavior in a multi-level desktop VE. The findings of this study can shed

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light on how interior architects can improve the design of real environments. The terms architectural cues and vertical navigation are considered separately in various studies by focusing on their qualitative properties. In addition, vertical navigation is not explicitly discussed. However, this study examines local architectural cues from an interior architecture perspective and proposes a heuristic for interior architects during virtual vertical navigation.

1.1. Navigation in VEs

With the increase in computer usage, VEs have become new areas of navigation and a tool for spatial knowledge acquisition since they offer the opportunity of controlling and manipulating the characteristics of a real world environment. They allow simulated exploration of three-dimensional (3D) environments from a view-centered perspective while creating environments at different complexity levels that are close to the real world conditions. In addition, they allow researchers to have greater control over visual features and investigate how people navigate and what navigation strategies they utilize in unfamiliar environments while interacting their navigation with continuous measurements (Dalgarno and Lee, 2010; Hardiess et al., 2015; Vilar et al., 2012; Walkowiak et al., 2015). Spatial knowledge acquired through learning the VEs can be effectively transferred to subsequent navigation in the real environments (Lessels and Ruddle, 2005; Walkowiak et al., 2015; Waller, 2000). The environmental structures and visual cues that play a role in acquiring spatial knowledge in a VE can effectively be utilized in real environments and improve the design of real environments. A VE for architectural use allows interior architects and clients to obtain an immersed view of a building by allowing the user to move through the designed building. It enables the individual to visualize, interact and navigate effectively with the virtual, 3D proposed spatial environment in real time (Çubukcu and Nasar, 2005; Kumoğlu Süzer and Olguntürk, 2018; Kumoğlu Süzer et al., 2018; Sancaktar and Demirkan, 2008).

Navigation is a coordinated and goal directed movement through an environment that consists of two parts, travel (locomotion) and wayfinding (Montello and Freundschuh, 2005). Travel is the actual motion from the current location to the new location, changing the position of the viewpoint and avoiding obstacles (Montello and Freundschuh, 2005; Zhang, 2008). The second constituent of navigation is wayfinding that refers to the “cognitive coordination to the distant environment, beyond direct sensorimotor access, and includes activities such as trip planning and route choice” (Montello and Freundschuh, 2005: 69) where the path is determined by knowledge of the environment, visual cues and navigational aids. Wayfinding emphasizes the mental processes of navigation while travel emphasizes the physical processes to execute navigation plans (Zhang, 2008). Navigation is a dynamic process where the task and the environment in which it takes place affects the way people move and determine their orientation (Särkelä et al., 2009). Spatial navigation in 3D environments like multi-level buildings can occur as horizontal or vertical navigation. Horizontal navigation is movement in the horizontal plane, whereas vertical navigation is movement in the vertical plane, between the levels of the building (Hinterecker et al., 2018; Hölscher et al., 2006; Thibault et al., 2013).

Since travel and wayfinding are closely related, the method of travel can have an effect on the ability to perform wayfinding tasks, in setting one's viewpoint position and in determining spatial orientation. In desktop VEs, the most common travel metaphor used for viewpoint control and navigating architectural buildings is virtual walkthrough (Lapointe and Savard, 2007; Lapointe et al., 2011). Bowman et al. (1999) categorized virtual travel techniques by the amount of control the users have over their motions as discrete target, continuous and one-time specifications. In discrete target specification, the user identifies the target and the system moves the user there, “the user controls the two-end points of motion and leaves the path between those points up to the system” (Bowman et al., 1999: 620). In continuous specification, there is a complete control of the user on the process of moving through an environment. In one-time route specification, there is no control of the user over the motion, in other words, the user defines a path of viewpoint motion and the system moves the user along that path. Likewise, in virtual travel, steering techniques, which allow continuous control of the direction of travel, are mainly used in VEs and they constitute of gaze-directed, pointing-directed and torso-directed steering (Suma et al., 2010). Gaze-directed steering is the simplest and most common method in which travel is in the direction the individual is looking, in pointing-directed steering, travel direction is indicated by the individual's hand and in torso-directed steering, and the individual's body (Suma et al., 2010) indicates travel direction. Since individual differences were important in the study, continuous specification and gaze-directed steering were chosen as the travel techniques.

1.1.1. Gender differences in VEs

Finding one's way in a multi-level building differs according to the adopted navigation strategy that affects the wayfinding performance in terms of wayfinding time and efficiency (Zijlstra et al., 2016). Studies have shown that males and females employ different types of strategies and focus on different properties of the environment during navigation (Castelli et al., 2008; Martens and Antonenko, 2012; Tlauka et al., 2005). Males employ a Euclidean approach in navigating to a target, using cardinal directions and absolute distance (survey strategy), whereas females use a topographic strategy that rely more on visual landmarks and egocentric directions (route strategy). Males form a more accurate representation of the Euclidean or geometric properties, whereas females form a more accurate representation of the landmarks in the 2D environment. Likewise, females are superior at using landmark-based strategies when navigating and they have better memories for identity and location of landmarks, whereas males have enhanced knowledge of the Euclidean properties of the environment that are distance and directional cues (Barkley and Gabriel, 2007; Chai and Jacobs, 2009; Chen et al., 2009; Coluccia and Louse, 2004; Iachini et al., 2005; Picucci et al., 2011; Sandstrom et al., 1998; Tlauka et al., 2005; Zimmerman and Li, 2010). Lin et al. (2012) found that female participants spend more time to locate targets, whereas male participants moved faster than females and traveled greater distances during virtual wayfinding. They claimed that this gender difference is caused by higher computer experience and increased exposure to video games and virtual environments of males.

1.1.2. Navigational abilities in VEs

Gender differences shape an individual's navigational abilities and in turn, navigational abilities influence gender. Gender differences and navigational abilities are two constitutes that affect the navigational behavior of the individual. Navigational abilities consist of sense of direction (SOD), sense of presence (SOP), and computer experience (CE) and computer familiarity (CF).

SOD is the ability to update one's orientation and location in space with body movement in the environment and one's ability to maintain their orientation to distal landmarks during navigation (Hegarty et al., 2002; Sholl et al., 2000). SOD is measured by using behavioral tasks, for example pointing to non-visible locations is the most common method or using a self-report measure (Hegarty et al., 2002; Hund and Nazarczuk, 2009; Sholl et al., 2000). People with a poor sense of direction (PSOD) usually cannot find the destination easily during travelling. They are more likely to lose their way, worry about becoming lost, and feel more anxious when they are lost (Padgitt and Hund, 2012; Sholl et al., 2000). People with a good sense of direction (GSOD) explore and focus on details in new environments, give and follow directions, and remember new routes. They orient the mental representation of the landmark configuration to correspond with the perceived environment better than do people with PSOD and are more accurate at pointing to locations (Cornell et al., 2003; Hund and Nazarczuk, 2009; Padgitt and Hund, 2012; Sholl et al., 2000). Previous studies asserted that people's self-reports of SOD are reliable predictors of spatial orientation and wayfinding, and SOD is positively correlated with orientation strategies and negatively correlated with route strategies (Hegarty et al., 2006; Hund and Nazarczuk, 2009; Kato and Takeuchi, 2003; Padgitt and Hund, 2012; Sholl et al., 2000). Padgitt and Hund (2012) found that people with a good self-reported SOD indicated higher ratings to survey descriptions consisting of cardinal directions, distances, left-rights and choice point landmarks, and made fewer wayfinding errors than did people with a poor self-reported SOD (Hartley et al., 2003; Hund and Nazarczuk, 2009; Hund and Padgitt, 2010). Controversial results exist with respect to gender differences and SOD. Nori and Piccardi (2011; 2015) and Piccardi et al. (2011) documented that men have a better SOD than women do. However, various studies did not find a consistent gender difference in the wayfinding task; but female participants rated their SOD as worse than males (Castelli et al., 2008; Cornell et al., 2003; Hund and Nazarczuk, 2009).

With the increase in computer usage, it has become important to understand the relationship between technology and human behavior. VEs enable users to experience, navigate and interact with virtual cues intuitively in real time. During this interaction, they often experience a sense of being in the VE, which is referred as presence in which they mentally remove themselves from the real world to the virtual world. In order to be fully spatially present in the VE, the individual has to forget about the physical environment and accept the VE as the only reference frame (Alsina-Jurnet and Gutiérrez-Maldonado, 2010; Riecke, 2003). In addition, the VE has to be immersive and easy to use so that the user does not pay attention to the equipment and experiences a sense of being there in the VE. Presence is a multi-dimensional construct that describes a psychological state of being in the VE without being aware of one's own actual physical environment (Lee and Kim, 2008; McCreery et al., 2013; Rebelo et al., 2011; Riecke, 2003; Sadowski and Stanney, 2002; Wissmath et al., 2011; Witmer and Singer, 1998). It implies that users perceive their self-orientation and self-location with respect to the VE (Riecke, 2003; Wissmath et al., 2011). Subjective ratings through questionnaires are the most commonly used measures in the presence research since presence is a subjective experience (Sadowski and Stanney, 2002). The experience of presence in VEs can vary according to individual differences, such as gender, previous experience, personality, cognitive abilities and cognitive style. In addition, it can vary according to domain-specific knowledge, and to the characteristics of media form and media content (Alsina-Jurnet and Gutiérrez-Maldonado, 2010; Hou et al., 2012; Lachlan and Krcmar, 2008; Lee and Kim, 2008; Lessiter et al., 2001; Sacau et al., 2008).

Previous experience of the individual, especially playing computer games, is one of the factors that can influence the attention given to certain objects or features during virtual navigation. Research has shown that playing computer games and utilizing computer applications can influence the spatial abilities of the individuals and enhance navigational abilities in virtual environments (Castel et al., 2005; Cherney, 2008; Green and Bavelier, 2003; 2006; Lin et al., 2012; Martens and Antonenko, 2012; Murias et al., 2016; Quaiser-Pohl et al., 2006; Richardson et al., 2011; Spence and Feng, 2010; Spence et al., 2009; Sungur and Boduroğlu, 2012; Ventura et al., 2013; Walkowiak et al., 2015). Green and Bavelier (2003) demonstrated that experienced computer game players (CGPs) outperformed novice computer game players (NCGPs) on tasks measuring the spatial distribution and resolution of visual attention, the efficiency of visual attention and the number of objects can be attended. They suggested that CGPs were better at detecting information in the virtual environment. Likewise, CGPs are faster and more accurate than NCGPs while navigating in a 3D environment (Boot et al., 2008; Burigat and Chittaro, 2007; Castel et al., 2005; Dye et al., 2009a; 2009b; Richardson et al., 2011). Waller (2000) stated that the ability to navigate through different interfaces and the ability to do them automatically represents a potential interfering factor resulting in males having greater experience in the use of computer and computer games than the females. In order to eliminate the differing ability, a training phase with the VE apparatus before the experimental session is provided (Castelli et al., 2008; Tlauka et al., 2005). Although interface proficiency, which is the individual's ability to use the keyboard keys to navigate through the simulation (Tlauka et al., 2005), is one of the predictors of learning in VEs (Waller, 2000), Tlauka et al. (2005) stated that initial training with the keyboard keys to navigate did not significantly associate with performance in the spatial tests.

The relationship between computer game experience and spatial ability revealed an advantage for males. Males are more experienced in activities that enhance the development of spatial skills; such as computer games and exploratory games, and are exposed to a higher spatial experience than females (Castelli et al., 2008; Coluccia and Louse, 2004; Lawton and Morrin, 1999). Lawton and Morrin (1999) showed that prior experience with computer games involving navigation through virtual environment resulted in higher pointing accuracies for males, since computer games were perceived as a masculine domain. Males reported to have more experience, more confidence and be more comfortable with computer games than females (Castelli et al., 2008; Cherney and London, 2006; Coluccia and Louse, 2004; Quaiser-Pohl et al., 2006). Females are generally slower than males when navigating (Lin et al., 2012; Sandstrom et al., 1998; Tlauka et al., 2005).

Because of the interaction with computers three constructs have been identified: computer aversion or anxiety, attitudes towards computers and experience with computers (computer familiarity) (Schulenberg and Melton, 2008; Schulenberg et al., 2006). Computer anxiety is a psychological phenomenon that is defined as aversion to computers, fear or apprehension towards dealing with computers and points out negative feelings (Beckers et al., 2006; Bozionelos, 2001; Schulenberg and Melton, 2008; Schulenberg et al., 2006; Tekinarslan, 2008; Teo, 2008). Bozionelos (2001) found that students with a high level of computer anxiety tend to avoid computers or general areas where computers are found, are cautious with computers, possess negative feelings about computers and shorten the use of computers. The most consistent correlate of computer anxiety is computer experience (Bozionelos, 2001). Computer experience is defined as the degree to which a person understands how to use a computer (Beckers and Schmidt, 2003). Smith et al. (1999) stated that computer experience as measured by computer use and 'the computer experience' should be differentiated. They referred to these terms as objective and subjective measures of computer experience, respectively. Researchers have focused on the objective measures of computer experience that is amount of computer use, opportunity to use computers and diversity of experience (Garland and Noyes, 2004; Smith et al., 1999; 2000). Variables such as computer usage level, usage frequency, computer ownership, computer education, and amount and breadth of time in computer usage are used as indicators of computer experience. It has been reported that increased computer experience and frequent usage of computer leads to lower levels of computer anxiety (Beckers and Schmidt, 2003; Bozionelos, 2004; Tekinarslan, 2008). Attitudes towards computers are cognitive in scope and are defined as positive or negative thoughts that individuals have about computers, their utility and their role in society (Schulenberg and Melton, 2008; Schulenberg et al., 2006). Computer attitudes can affect individual behaviors and this will influence the individual's use of computers (Garland and Noyes, 2004). Smith et al. (1999) defined subjective computer experience as feelings or emotions that are stimulated by computers. Computer attitudes correlate positively with computer experience; the more experience an individual has with computers the more likely they are to express positive attitudes (Bozionelos, 2001; Garland and Noyes, 2004; Smith et al., 1999; Teo, 2008). Computer aversion, attitudes towards computers and computer experience are related constructs (Schulenberg et al., 2006), in order to assess these constructs various measures are identified for each construct separately. However, the index developed by Schulenberg et al. (2006) assessed the three computer related constructs in a single measure referred to as the Computer Aversion, Attitudes and Familiarity Index (CAAFI).

1.2. Affordances in VEs

People typically act within an environment in order to achieve a goal or perform a task. This interaction between the environment and the user is based on the theory of affordance (Gibson, 1979). Gibson (1979) proposed that people visually guide their behavior by perceiving what action possibilities are offered by the environment and defined the affordances of an environment as “what it offers the animal, what it provides or furnishes, either for good or ill” (Gibson, 1979: 127). In other words, affordances are properties of the environment that when perceived, afford or provide an opportunity to perform some action. Affordances, as action possibilities, are “the things that a given animal can do in a given environment or situation” (Stoffregen and Mantel, 2015: 257). For example, a staircase in an environment has the affordance of climbing because of its dimension such as shape, height and type. The user's ability to climb, the length of their legs, their age and their weight enables them to climb the stairs (Cesari et al., 2003; Warren, 1984).

The theory of affordances is of interest in the field of human-computer interaction (HCI) that studies the interaction between people and computers (the environment) (Van Vugt et al., 2006). HCI is not only an interdisciplinary field, but also a science of design that consists of a reflective conversation between the user and the environment (Blackwell, 2015; Carroll, 1997; Reeves, 2015; Schön, 1987). For the user to recognize the potential for action, affordances must be properly perceived. According to Shin (2017) the theory of affordance is a pragmatic concept that guides design decisions in developing functional and easily perceivable cues for the user. Designers are aware that affordances can be perceived by users and the design of the environment should enable the perception of an object's affordances (Stoffregen and Mantel, 2015). The perception of affordances is highly dependent upon user navigation (Stoffregen and Mantel, 2015) and perceived affordances refer to a user's perception of action possibilities through cues in the surrounding environment.

In a VE, affordances are inferred through technological design characteristics that are visual cues of the environment or salient cues gathered by the user as action possibilities (Gibson, 1979; Tang and Zhang, 2018). Users navigating in a VE perceive, experience the affordances that are available to them in terms of action possibilities for goal achievement and actively engage with events in the environment, rather than being passive recipients (Dalgarno and Lee, 2010). Gibson (1979) conceptualized visual cues as information that “does not stimulate a passive receiver but instead allows the user the active role of noticing and utilizing the information” (Shin, 2017: 1828). As there are various affordances in a VE, it is important to design visual cues that afford action possibilities for users and engage them with the intended task. Perceptible information such as architectural cues in a VE impacts users’ perception of affordances.

1.3. Architectural cues

When people navigate in unfamiliar VEs, the design of the VE should promote rapid information that is necessary for successful navigation and orientation. Navigators need to develop accurate spatial information as quickly as possible when information is represented by the relative size, orientation and position of virtual objects. Navigation and orientation in the VE could be enhanced by cues that people use while navigating in the real environments. These cues are comprised of all kinds of information that is available in the environment, such as ‘verbal’, ‘graphic’, ‘architectural’ and ‘spatial’ cues (Sun and de Vries, 2009). An architectural cue is a piece of information hinted by an architectural element in the environment (Sun and de Vries, 2009). Dijkstra et al. (2014) asserted that the influence of architectural cues on user's navigation in the environment is underestimated. Understanding the influence of architectural cues on the user can inform interior architects and designers about how to design facilities. Sun and de Vries (2009) stated that an architectural cue is essential in the environment and is configured by the architects in the initial phase during design process. In the initial phase, the architectural space, which is composed of architectural cues, can offer a variety of meanings to the perceived users and have an impact on their behavior patterns (Sun and de Vries, 2009). Architectural cues do not only indicate a reference to position and orientation, but they also contribute to the development of spatial knowledge. They are categorized as global and local architectural cues (Sun, 2009).

Sun (2009) stated that global architectural cues are perceived from the architectural forms. They provide information about how the parts of the building are organized globally. They serve as references to absolute location and provide a stable frame of reference (Lin et al., 2012; Sun, 2009). Global architectural cues as the built environment part are: the circulation system, the exterior form of the building, the visible structural frameworks and the atrium (Arthur and Passini, 1992; Sun, 2009). According to Arthur and Passini (1992), the circulation system is the main organizing feature and a determining factor for the layout of an environment. The circulation system determines the space in which people travel, try to understand, find their way and make wayfinding decisions. When people navigate in the circulation system of a building, they are able to understand the spatial organization and the typology of the system. The exterior form of a building provides clues about the spatial organization and circulation system. Likewise, the visible structural framework inside a building gives clues about the spatial organization. The atrium provides the individuals with a visual and sometimes auditory access to the spatial organization of the building (Arthur and Passini, 1992; Sun, 2009).

The local architectural cue is based on the features of the architectural elements that are locally perceivable (Lin et al., 2012; Sun and de Vries, 2009). In other words, it is a type of information that is perceived from the architectural forms and is based on the abstract 3D geometric attributes of the local architectural elements, such as doorway entrances, stairs, exits and corridors (Kelly et al., 2008; Lin et al., 2012; Sun, 2009). Various studies investigated individual's preference of local architectural cues in virtual environments and proposed behavior simulations based on evacuation of buildings (Chen, 2012; Sun, 2009; Sun and de Vries, 2009). Sun (2009) deduced a list of local architectural cues that were influential during an evacuation from an underground space. These were vertical outdoor light, stair, doorway entrance, raised ceiling, columns, lighted ceiling, escalator, handrail and lift from the most attractive to the least (Sun and de Vries, 2009). Arthur and Passini (1992) specified four types of local architectural cues that define a circulation system: the entrance, which gave access to the building, the exit, which indicated where to leave the building, the path, which indicated the direction of movement and where to enter the other spaces, and the vertical access, which indicated where to go in order to change levels within the building (Arthur and Passini, 1992; Sun, 2009). In addition, Sun (2009) identified four types of sources that determine the local architectural cues. These consist of the type of the architectural element in the circulation system, distance from the architectural element to the individual, scale of the architectural element and angular position of the architectural element with respect to the individual's view (Sun, 2009).

Local architectural cues are seen as salient landmarks that mark a location and used as reference points. The salience of landmarks refers to the distinctiveness of the cue that are determined by structural, visual and semantic qualities (Balaban et al., 2017; Caduff and Timpf, 2008; Davis and Ohman, 2016; Karimpur et al., 2016; Viaene et al., 2014). Staircases are structurally salient due to their

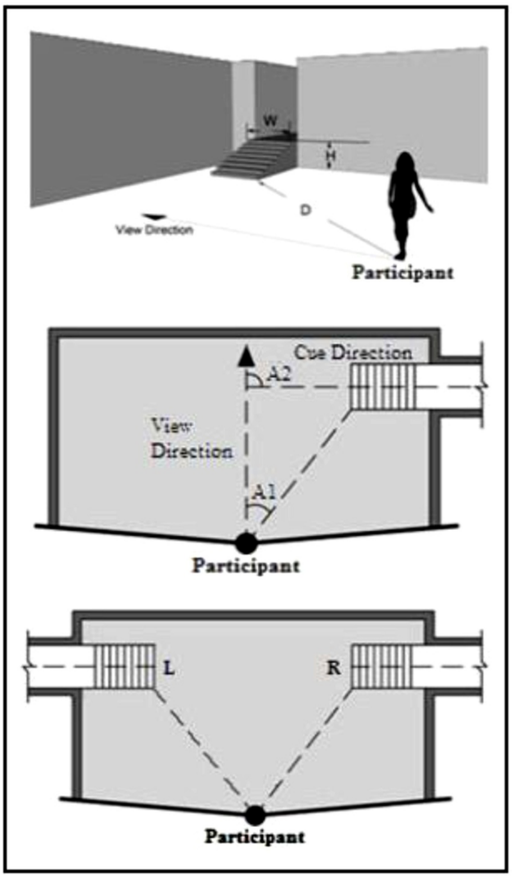

Fig. 1. Attributes of a Staircase (Adapted from Sun, 2009: 94).

prominent spatial location serving as circulation nodes (Hölscher et al., 2006; Li et al., 2018). Staircases enable vertical navigation between different levels of a building and provide access to various levels. Nicoll (2007) stated that staircase use is an underlying activity of purposeful travel and is affected by the way people understand and travel through buildings. Olander (2009) claimed that environmental variables such as staircase location and visibility, staircase and building height and escalator/lift availability have an impact on staircase use. Staircases are utilized more when they are conveniently located closer to the entrance and are visible. According to Nicoll (2007), staircase use is influenced by the placement of the staircase rather than the appearance of the staircase. In addition, the most prominent spatial measures that increase stair usage are stair width and stair type. The geometric attributes of a staircase are defined as (see Fig. 1):

- the distance from the cue to observation point of the participant (D),
- the width of the cue (W),
- the height of the cue (H),
- the place of the cue with respect to the participant's view direction (Left (L) or Right (R)),
- the angle between the view direction and the cue (A1), and
- the angle between the view direction and the cue direction (A2).

'View direction' can be defined as the facing orientation of the participant, in other words, the direction of the participant's view from his/her current position in which his/her head and body are in a straight line. 'Cue direction' is the direction of the cue.

1.4. The current research

The study utilizes the VE as a medium for investigating the role of staircases since the geometric attributes of the staircases could be varied systematically in order to understand their influence on vertical navigation. Vertical navigation is examined by integrating the characteristics of the individuals and the staircase preferences within two different multi-level desktop VEs. The research questions are stated as:

1 Is there a difference in preference for ascending and descending staircases in the VE?
  a In a VE with a 90° difference between the cue pairs (Set 1)
  b In a VE with a 180° difference between the cue pairs (Set 2)
2 Is there a relationship between gender and the staircase preferences in the VE?
  a In a VE with a 90° difference between the cue pairs (Set 1)
  b In a VE with a 180° difference between the cue pairs (Set 2)
3 Is there a relationship between the navigational abilities and the staircase preferences in the VE?
  a In a VE with a 90° difference between the cue pairs (Set 1)
  b In a VE with a 180° difference between the cue pairs (Set 2)
4 Is there a difference between a cue pair of a 90°difference and a 180° difference with respect to the virtual navigation?
  a Circulation path
  b Staircase preference
  c Virtual navigation total duration

Accordingly, the hypotheses are:

1 There is a significant difference in preference for ascending and descending staircases in the VE.
2 There is a significant relationship between gender and the staircase preferences in the VE.
3 There is a significant relationship between the navigational abilities and the staircase preferences in the VE.
4 There are significant differences between a cue pair of a 90° difference and a 180° difference with respect to the circulation path, staircase preferences and virtual navigation total duration.

2. Method

2.1. Participants

The sample group consisted of undergraduate students from the department of Interior Architecture and Environmental Design (IAED) at İ. D. Bilkent University. One hundred and eighty senior students were randomly selected according to gender from the 4th year 'Interior Design' studio with cluster sampling. All the participants provided the written informed consent form and the Ethics Committee of İ. D. Bilkent University approved this study. As 4th year students, they were familiar with computer-based environments due to the computer-based courses that they took during the second and third years of their education and had sufficient design education background. There were an equal number of female and male participants whose age range was from 18 to 34 with a mean age of 22.39 years (SD = 2.17). The majority were right-handed with only 13 left-handed participants. The participants were randomly assigned to the experimental conditions.

2.2. Software and instruments

The 3D VEs consisted of two storey high buildings designed in Second Life (SL). SL is a computer-simulated 3D environment that is elaborated by the participation of its users (Secondlife, 2019). SL enables real-time interactions and offers its users the possibility to build virtual spaces and objects, and personify their avatars through a user-friendly interface (Hendaoui et al., 2008; Wu et al., 2015). Users are able to navigate by walking, flying and teleporting between spaces and other movement types such as jumping and running are available. Interaction in the 3D environment is through an avatar, i.e. first-person viewpoint, or over the avatar, i.e. third-person viewpoint in which they see the avatar. Navigation in SL is manipulated with a keyboard and a mouse changes the direction of view (Wu et al., 2015).

Participants were asked to fill out a pen and paper battery of questionnaires before and after the virtual navigation, which consisted of the following measurements:

- Santa Barbara Sense of Direction Scale (SBSOD):

The SBSOD questionnaire consists of 15 items on a 1–7 Likert scale containing eight positive and seven negative statements about spatial and navigational abilities, navigational aptitudes and experience. Once the scores on the items containing positive statements are inverted, the total score is calculated by totaling the individual scores. A low score corresponds to a greater sense of self-perceived direction (Hegarty et al., 2002). When people rate their SOD as good or poor, they base their judgments on environment tasks such as wayfinding, remaining oriented in an environment, learning layouts, using maps to navigate, giving, and following directions. The SBSOD reflects the ability to orient oneself in an environment (Hegarty et al., 2002).

- Computer Aversion, Attitudes and Familiarity Index (CAAFI):

The CAAFI comprises of 30 items that help to understand better computer aversion, attitudes toward computers and CF. The CAAFI utilizes a 7-point Likert scale that ranges from −3 (absolutely false) to +3 (absolutely true). It contains positively and negatively worded items with some items needing reverse scoring. When the items are summed, a high positive score indicates less computer aversion, more favorable computer-related attitudes and greater familiarity (Schulenberg and Melton, 2008).

- Igroup Presence Questionnaire (IPQ):

The IPQ is a scale for measuring the SOP experienced in the VE that consists of 14 items rated on a 7 point rating scale that ranges from −3 to 3 (Schubert et al., 2001). It consists of one general item, five items for 'spatial presence', four items for 'involvement' and four items for 'realness'. The general item that assesses the general 'sense of being there' has high loadings on the 3 factors with a strong loading on 'spatial presence' (Igroup 2016). Three items are reversed in scoring among all the items that have a range from 1 to 7. By answering the items, the spatial presence of the participants was verified.

- Observation Sheet and Computer Experience Questionnaire (CEQ)

An observation sheet was developed to record the virtual navigation of the participants. It comprises of the participants characteristics that consist of the participant's, age, gender and handedness (left-right handed), and the virtual navigation characteristics that consist of the circulation path, staircase preference and their reasons, navigation durations on the ground floor and first floors, and the virtual navigation total durations (i.e. starting and ending at the entrance after bringing the gift box to the entrance) for the virtual environments. The CEQ was developed in order to understand the participant's knowledge about SL, their ability to play computer games, frequency of playing computer games, years of playing computer games and the types of computer games they played. The CEQ is different from the CAAFI since the CAAFI did not assess these variables.

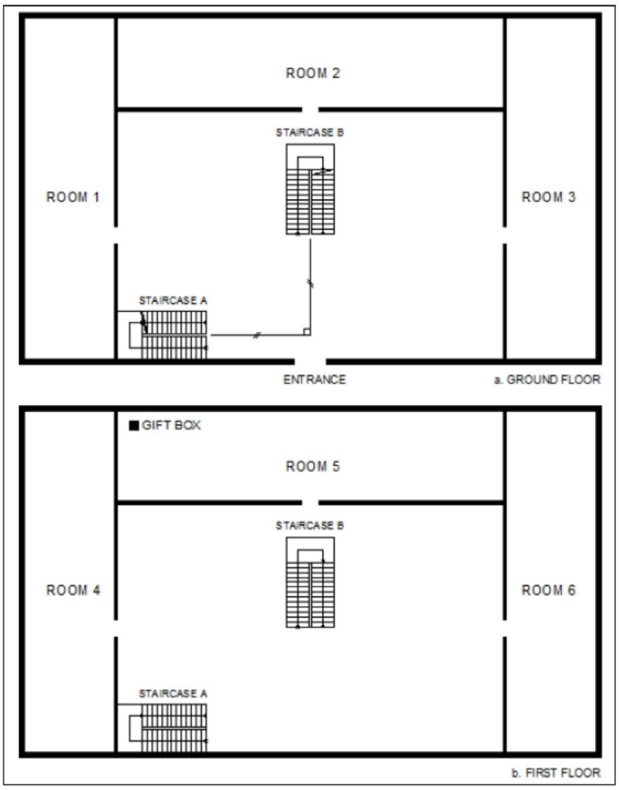

Fig. 2. Set 1: An angle difference of 90° between the cue pair (a: Ground floor, b: First floor).

2.3. Experimental setting

The desktop VE consisted of two environmental spaces (referred to as Set 1 and Set 2) that contained two staircases (cue pair) each as the local architectural cues and six rooms as three on the ground floor and three on the first floor. Each environmental space was 21 m x 35 m x 7.8 m. Each set had a different angle between the cue directions in a cue pair from the observation point. In Set 1, the cue pair was positioned perpendicular and the angle between the cue directions was 90° (see Fig. 2). In Set 2, the angle between the cue directions was 180° (see Fig. 3). In Set 1, the cue pair was located in the middle and on the left side of the entrance (see Fig. 4). In Set 2, the cue pair was located on both sides of the entrance (see Fig. 5).

In Set 1, the participants could view the cue pair at the same time due to the binocular field of view that covers a region of about 120° (Henson, 1993); however, in Set 2, the locations of the cue pair exceeded the binocular field of view of 120°. To eliminate any biases in staircase preferences that were formed at the entrance, the participants were told to visit all the rooms until they found a gift box. A gift box, which was distinguishable from the surrounding (see Fig. 6), was placed on the first floor in the middle room (see Figs. 2b and 3b; Room 5). To eliminate the effect of color in the experiment, the interior of the VEs and the cue pairs were between the black-white scales. The width and height of the staircases and the distance from the staircases to the observation point were kept constant.

The participants have full control over their movements in the VE; this is referred to as continuous specification. The participants navigate from a first-person viewpoint and they are able to navigate in the VE by utilizing the arrows on the keyboard and the mouse for the direction of their viewpoint. Three separate pilot studies were conducted. The first pilot study was carried out with eight participants to test the clarity of the questionnaires, and the usability and design of the building in the

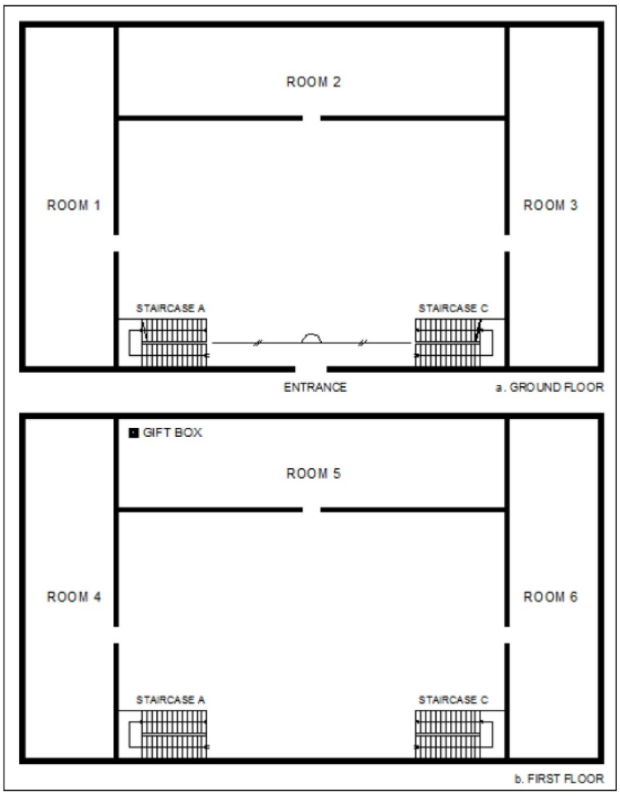

Fig. 3. Set 2: An angle difference of 180° between the cue pair (a: Ground floor, b: First floor).

VE. The next two pilot studies, which were done with four participants each, detailed the design of the virtual building. These participants were not included in the experiment.

2.4. Procedure

2.4.1. Phase I: pre-test questionnaire

The study was conducted in three phases. In the first phase, two questionnaires were administered: SBSOD and CAAFI. According to the SBSOD results of the 180 participants, participants below the mean were grouped as GSOD and those who were above the mean were grouped as PSOD. In the CAAFI, items related to CF were considered in the study in order to assess the participants' familiarity with the computer. According to the CF results of the 180 participants, participants below the mean were grouped as 'poor' (PCF) and those who were above the mean were grouped as 'good' (GCF).

2.4.2. Phase II: testing on computer

In the second phase, the participants were seated approximately 50 cm from the computer and tested individually in each gender group. They navigated the desktop VE from an egocentric frame of reference by either utilizing the up-down-right-left arrows or the 'W', 'A', 'S' and 'D' keys for walking and the mouse for changing their viewpoints. The egocentric frame of reference is determined by the position of the participant in the environment and is based on subject-to-object relations (Mou et al., 2004). Each participant was given 3 min to acquaint themselves with the keyboard and mouse within the SL environment. They navigated in an open environment to become familiar with the virtual world.

The participants were told to explore the ground floor and then the first floor, get the gift box and return to the entrance. Two independent samples, each consisting of 90 participants (45 female and 45 male) alternately navigated the two sets with the angle differences of 90° and 180° between the cue pairs. While navigating in the VE, each participant's characteristics and virtual navigation characteristics were recorded separately for Set 1 and Set 2 on the observation sheet. The interaction between the participant and the VE leads to vertical navigation in which the participants indicate their reasons for choosing a staircase for ascending and descending in the desktop VE. While navigating in the VE, the utilization of a cue within the cue pair affects the order of room visits, for example, choosing a specific cue for ascending influences the order of room visits on the first floor of the VE, likewise the order of room visits influences the utilization of a cue for ascending and descending. As a result, this determines the navigation duration and vertical navigation. The interactions within Set 1 and Set 2 are compared in order to understand which cue is efficient during vertical navigation in the VE.

For both sets, six alternative routes for the ground floor and five alternative routes for the first floor were identified as the circulation paths. Participants could navigate the rooms on the ground and first floors in any order. Since the gift box was located in the middle room of the first floor, participants had the chance of directly choosing the middle room before visiting the other rooms of the first floor. After finding the gift box, they did not visit the other rooms, but returned to the entrance. For the staircase preferences, four alternative routes were determined for both sets in the VE. Participants could either utilize the same staircase for ascending and descending or the reverse (i.e. one for ascending and the other for descending).

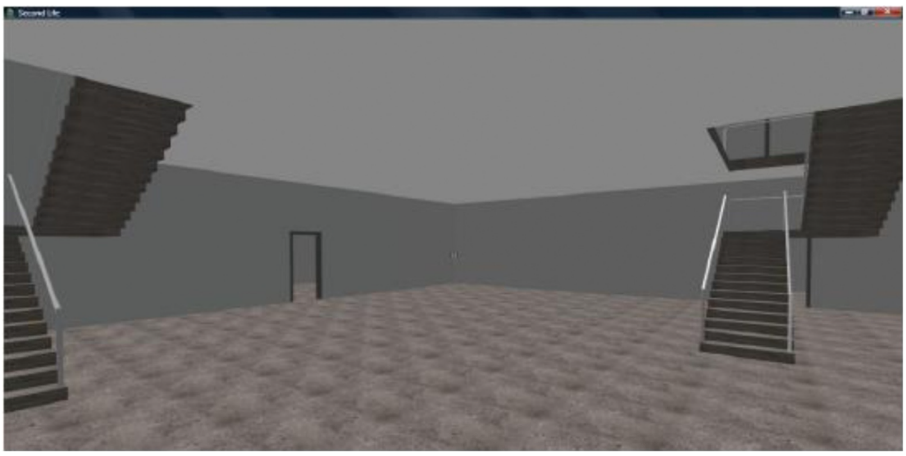

Fig. 4. Set 1: A view from the entrance towards the cue pair.

Fig. 5. Set 2: A view from Room 2 towards the cue pair and entrance.

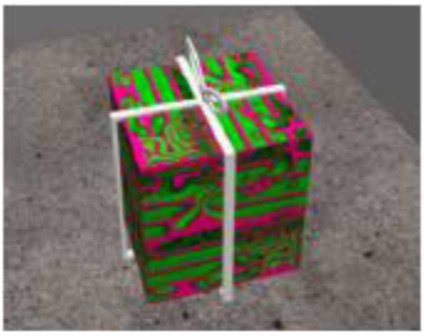

Fig. 6. Gift box.

2.4.3. Phase III: post-test questionnaire

After navigating in the VE, the participants rated their level of presence in the VE by answering the questions in the IPQ. The assessment of SOP was important because the participants had to feel present in order to orient themselves. Then the CEQ was administered to assess the participants' prior experience with computers.

3. Results

3.1. Related to the staircase preferences within each VE

The correlated *t*-tests, chi-squares, analysis of variance (ANOVA) and independent *t*-tests were used to examine the staircase preferences by focusing on the ascending and descending preferences, and ascending preferences according to the first and last visited rooms in each VE.

3.1.1. Related to the ascending and descending preferences of the staircases within each VE

The staircase preferences for ascending and descending were assessed within each VE with the cue pairs by using a correlated *t*-test. In Set 1, there was no significant difference between the ascending and descending staircases ($M = 1.63$, SD = 0.49 and $M = 1.67$, SD = 0.47, respectively); and there was no correlation between the ascending and descending staircases. In Set 2, the two means did not differ significantly ($M = 1.93$, SD = 1.00 and $M = 2.18$, SD = 0.99, respectively). However, the correlation test showed that there was a positive low relationship ($r = 0.24$, df = 88, $p < 0.024$) between the ascending and descending staircases.

3.1.2. Staircase preferences for ascending according to the first visited room

In Set 1, there was no significant relationship between the first visited room on the ground floor circulation path and the staircase preference for ascending. However, for Set 2, there was a significant relationship between the first visited room on the ground floor circulation path and the staircase preference for ascending ($\chi^2 = 15.82$, df = 2, $p \leq 0.0001$).

ANOVA was conducted to find if the staircase preferences for ascending according to the first visited room on the ground floor had different means in Set 2. The effect of the first visited room was significant overall ($F_{2,87} = 9.28$, $p \leq 0.0001$). When a Bonferroni adjustment was made for the number of comparisons, there was no significant difference between the means of Room 1 and Room 2; however, there were two significant differences. The mean of Room 1 ($M = 2.65$, SD = 0.79) was significantly higher ($t = 4.33$, df = 61, two-tailed $p \leq 0.0001$) than that of Room 3 ($M = 1.57$, SD = 0.91) and the mean of Room 2 ($M = 2.11$, SD = 1.01) was significantly higher ($t = 2.37$, df = 71, two-tailed $p \leq 0.020$) than that of Room 3 ($M = 1.57$, SD = 0.91).

3.1.3. Staircase preferences for ascending according to the last visited room

In Set 1, there was no significant relationship between the last visited room on the ground floor circulation path and the staircase preference for ascending. However, for Set 2, there was a significant relationship between the last visited room on the ground floor circulation path and the staircase preference for ascending ($\chi^2 = 8.51$, df = 2, $p \leq 0.014$). ANOVA was conducted to find if the staircase preferences for ascending according to the last visited room on the ground floor had different means in Set 2. The effect of the last visited room was significant overall ($F_{2,87} = 4.54$, $p \leq 0.013$). When a Bonferroni adjustment was made for the number of comparisons, the only significant difference was between the means of Room 1 and Room 3 ($t = -2.67$, df = 81, two-tailed $p \leq 0.009$). The mean of Room 3 ($M = 2.27$, SD = 0.98) was significantly greater than that of Room 1 ($M = 1.68$, SD = 0.96). There were no significant differences between the means of Room 1 and Room 2 and between Room 2 and Room 3.

In order to understand which staircase for ascending was preferred during the virtual navigation according to the circulation paths of the ground floor in both sets, an independent *t*-test was conducted. According to the circulation path of the ground floor with respect to the first and last visited rooms in Set 1, there were no significant differences between Staircase A and Staircase B (see Fig. 2). However, according to the circulation path of the ground floor with respect to the first visited room in Set 2 (see Fig. 3), the mean of Staircase A ($M = 2.63$, SD = 0.61) was significantly higher ($t = 4.33$, df = 88, two-tailed

Table 1
Staircase preferences - ascending and descending within each VE.

	Set 1	Set 2
Ascend - Descend	No Correlation	Low (+) Correlation
1st Room - Ground flr.	No Correlation	Room 1 > Room 3 < Room 2
Last Room - Ground flr.	No Correlation	Room 3 > Room 1 *Room 1 = Room 2, Room 2 = Room 3*
Stair. pref. acc. to 1st Room - Ground flr.	*A = B*	*A > C*
Stair. pref. acc. to Last Room - Ground flr.	*A = B*	*A < C*

Table 3
Distribution of sense of direction and computer familiarity scores within each set according to gender.

Gender	Sense of Direction	Computer Familiarity in Set 1 PCF	GCF	Total	Computer Familiarity in Set 2 PCF	GCF	Total
Female	GSOD	12	7	19	10	9	19
	PSOD	18	8	26	14	12	26
Male	GSOD	6	24	30	13	14	27
	PSOD	4	11	15	10	8	18

$p \leq 0.0001$) than that of Staircase C ($M = 1.98$, SD$=0.81$). With respect to the last visited room on the ground floor, the mean of Staircase C ($M = 2.02$, SD$=0.95$) was significantly higher ($t=-2.70$, df$=88$, two-tailed $p \leq 0.007$) than that of Staircase A ($M = 1.50$, SD$=0.85$). Table 1 depicts a summary of the ascending and descending preferences of the staircases, and the staircase preferences for ascending according to the first and last visited rooms within each set.

3.2. *Related to gender differences within the experiment*

In each experiment set, there were 90 participants with an equal number of female and male participants. The gender differences were examined with respect to SOD, CF, CE, SOP and properties of the virtual navigation, i.e. first visited room, staircase preferences and virtual navigation total durations within Set 1 and Set 2.

3.2.1. *Gender differences and SOD*

According to the results of the SBSOD questionnaire, the mean score was 3.43 (SD$=0.90$). Participants, who were below the mean, were grouped as having GSOD and those who were above the mean were grouped as having PSOD. Fifty-seven male and 38 female participants revealed to have GSOD, whereas 33 male and 52 female participants had PSOD.

According to the chi-square analysis, there was a significant relationship between gender and the scores obtained from the SBSOD questionnaire for Set 1 ($\chi^2=5.42$, df$=1$, $p \leq 0.020$); however, there was no significant relationship between gender and the scores obtained from the SBSOD questionnaire for Set 2. In order to test whether the means of the SBSOD questionnaire for female and male participants were different, an independent *t*-test was conducted. According to the independent *t*-test, there was a significant difference in gender with respect to SOD. In Set 1, the mean SOD scores of female participants ($M = 1.58$, SD$=0.50$) was significantly higher ($t = 2.38$, df$=88$, two-tailed $p \leq 0.020$) than that of male participants ($M = 1.33$, SD$=0.48$).

3.2.2. *Gender differences and SOP*

In the IPQ, the participants rated the general item and the three factors of 'spatial presence', 'involvement' and 'realness' as 5.17 (SD$=1.40$), 4.58 (SD$=0.92$), 3.74 (SD$=1.10$) and 3.43 (SD$=0.83$), respectively. For the general item and the three factors, scores were classified according to the mean score as below (PSOP) and above the mean (GSOP). The mean (M) and standard deviation (SD) values of the IPQ factors for each gender is depicted in Table 2. Male participants evaluated the factors except for the 'involvement' factor higher than the female participants did.

Table 2
Group statistics for gender and IPQ.

Gender	General Item M	SD	Spatial Presence M	SD	Involvement M	SD	Realness M	SD
Female	5.07	1.43	4.56	1.00	3.87	1.19	3.41	0.89
Male	5.27	1.36	4.60	0.84	3.61	0.99	3.45	0.77

According to this classification, 133 participants rated the general item as having themselves a good sense of 'being there' in the VE. For the factors 'spatial presence' and 'realness', 97 of the participants felt present in the VE and indicated the VE to be consistent with the real world, in addition, 95 participants indicated that they were aware of the VE. Chi-square analysis indicated that there were no significant relationships between gender and the factors of the IPQ for Set 1 and Set 2. As a result, gender was independent from the SOP in Set 1 and Set 2.

3.2.3. *Gender differences and CF and CE*

The mean score for the CF factor of CAAFI was 5.46 (SD$=12.28$) and the range was from -30 to 29. Participants were grouped into two categories according to the mean score as below (PCF) and above the mean (GCF). Fifty-seven male participants and 36 female participants indicated GCF. Overall 51.67% of the participants had good familiarity with the computer. Table 3 depicts the distribution of the participants according to gender, SOD and CF within each set. According to the distribution, the majority of the female participants with a PSOD expressed their CF as being poor; however, this was the reverse for the male participants in both sets.

Chi-square analysis indicated that there was a significant relationship between gender and the scores obtained from the CF questionnaire for Set 1 ($\chi^2=18.00$, df$=1$, $p \leq 0.0001$); however, there was no significant relationship for Set 2. According to the independent sample *t*-test, there was a significant difference between gender and CF in Set 1. The mean CF scores of female participants ($M = 1.67$, SD$=0.48$) was significantly higher ($t = 4.69$, df$=88$, two-tailed $p \leq 0.0001$) than that of male participants ($M = 1.22$, SD$=0.42$).

In the CEQ, 80 participants out of 180 indicated that they heard about SL, but only 26 participants used SL before and they mainly used it once. One hundred and fifty participants played computer games and they either played them less than once in a week (31.7%) or more than once in a week (32.2%). The mean year for playing computer games was 11.70 years (SD$=4.06$). The years for playing computer games were grouped into four categories as 1–9 years (21.05%), 10–11 years (27.63%), 12–14 years (21.71%) and 15–22 years (29.61%). This classification was formed according to the 25th, 50th and 75th percentiles, since statistical analysis could not be conducted for equal class intervals. Twelve genres for computer games were identified from the responses of the participants; these were strategy, role-playing, shooting, sports, racing, action and adventure, fighting, simulation, puzzle, platformer, arcade and play station. However, only the 'shooting' genre was considered in the evaluation since the viewpoint of the participant, which was first person point of view, the structure of the environment in the shooting games, and the usage of the keyboard and mouse couple were similar to the environment in the VE. According to the specified computer game genre, participants were grouped as whether or not they played this genre. Out of 150 who played computer games, only 64 participants played 'shooting' games.

To determine if CE was independent from gender, chi-square analyses were conducted for Set 1 and Set 2. In Set 1, there was a significant relationship between gender and playing computer games ($\chi^2=4.87$, df=1, $p \leq 0.027$). There was a significant relationship between gender and frequency of playing computer games ($\chi^2=16.97$, df=2, $p \leq 0.0001$). In addition, there were significant relationships between gender and playing computer games in years, and between gender and playing games with a shooting genre ($\chi^2=30.06$, df=3, $p \leq 0.0001$ and $\chi^2=18.31$, df=1, $p \leq 0.0001$, respectively). In Set 2, there was a significant relationship between gender and playing computer games ($\chi^2=8.46$, df=1, $p \leq 0.004$). However, there was no significant relationship between gender and frequency of playing computer games. There were significant relationships between gender and playing computer games in years, and between gender and playing games with a shooting genre ($\chi^2=24.68$, df=3, $p \leq 0.0001$ and $\chi^2=18.06$, df=1, $p \leq 0.0001$, respectively).

According to the independent *t*-tests for Set 1, there was a significant difference between gender and playing computer games. The mean number of female participants that play computer games ($M = 1.27$, SD=0.45) was significantly higher ($t = 2.24$, df=88, two-tailed $p \leq 0.027$) than that of male participants ($M = 1.09$, SD=0.29). There was a significant difference between gender and frequency of playing computer games. The mean of frequency of playing computer games of male participants ($M = 2.34$, SD=0.79) was significantly higher ($t=-3.96$, df=72, two-tailed $p \leq 0.0001$) than that of female participants ($M = 1.58$, SD=0.87). Male participants played computer games more than once in a week, whereas female participants played less than once in a week. There was a significant difference between gender and playing computer games in years. The mean years of playing computer games of male participants ($M = 3.10$, SD=0.83) was significantly higher ($t=-6.64$, df=72, two-tailed $p \leq 0.0001$) than that of female participants ($M = 1.76$, SD=0.90). Male participants played computer games longer than female participants did. In addition, there was a significant difference between gender and playing shooting games. The mean number of female participants that play shooting games ($M = 1.88$, SD=0.33) was significantly higher ($t = 4.87$, df=72, two-tailed $p \leq 0.0001$) than that of male participants ($M = 1.39$, SD=0.49).

According to the independent *t*-tests for Set 2, there was a significant difference between gender and playing computer games. The mean number of female participants that play computer games ($M = 1.27$, SD=0.45) was significantly higher ($t = 3.02$, df=88, two-tailed $p \leq 0.003$) than that of male participants ($M = 1.04$, SD=0.21). There was no significant difference between gender and frequency of playing computer games; however, there was a significant difference between gender and playing computer games in years. The mean years of playing computer games of male participants ($M = 3.16$, SD=0.88) was significantly higher ($t=-4.55$, df=76, two-tailed $p \leq 0.0001$) than that of female participants ($M = 2.09$, SD=1.19). Male participants played computer games longer than female participants did. In addition, there was a significant difference between gender and playing shooting games. The mean number of female participants that play shooting games ($M = 1.82$, SD=0.39) was significantly higher ($t = 4.79$, df=76, two-tailed $p \leq 0.0001$) than that of male participants ($M = 1.34$, SD=0.48).

3.2.4. Gender differences during the virtual navigation

In order to understand the reasons behind the staircase preferences, 28 items were identified from the participants' responses from the open-ended questions for Set 1 and Set 2. These items were classified under five attributes as 1. Distance, 2. Angular Position, 3. View Direction, 4. Personal Feeling and 5. Personal Preference. The first three attributes were formed with respect to the definition of a geometric attribute, the latter were based on the feelings, and preferences of participants (see Table 4).

The 'distance' indicated the proximity between the participant, exit and the last visited room. The visibility of the environment, the perception of the first floor and the orientation (climbing direction) of the staircase with respect to the participant were defined under the heading 'angular position'. In the 'view direction' attribute, two relationships were identified; the relationship between the participant and the staircase was clarified by the direction of the cue according to the participant's right left or front and circulation path. The second relationship was between the entrance and the participant; the direction of the cue was described with respect to the entrance. The participants indicated their feelings towards the staircase as being safer, easier, comfortable and private, and the importance of the staircase under the attribute 'personal feeling'. The 'personal preference' attribute indicated the participants' personal reasons for choosing a specific staircase during navigation in the VE.

According to the results of Set 1, there were a similar number of participants in choosing Room 1 and Room 3 as their starting point of navigation on the ground floor. On the first floor, more than half of the participants started at Room 6 (see Table 5). Thirty-eight participants utilized the staircase in the middle for ascending and descending (see Table 6). The reason for choosing this staircase was due to the 'angular position' and 'distance' attributes; it was in the center and close to the last visited room.

Table 4
Classification of the reasons for utilizing the staircases.

1. Distance	
11.	Close to the last visited room
12.	Close to me
13.	Close to the exit
2. Angular position	
21.	In the center, close to everywhere
22.	The idea of the first floor being perceived better
23.	Not to turn, was on a straight line
24.	This staircase had an orientation, whereas the steps of the other staircase was on the opposite side
3. View direction	
31.	The first staircase that I saw from the entrance door
32.	In front of the room that I last visited, within the point of view
33.	In front of the exit/entrance when descending
34.	On my right
35.	On my left
36.	According to the direction of the circulation path, starting from the left and finishing on the right
37.	On the right side of the entrance
38.	On the left side of the entrance
4. Personal feeling	
41.	The staircase in the middle was like the primary staircase
42.	The staircase on the sidewall was like a fire exit staircase
43.	Being in the middle seemed more safer
44.	Being on the side wall seemed more safer
45.	Going up/down from this staircase was easier
46.	Being in the corner made be uncomfortable
47.	The staircase on the sidewall seemed more private
5. Personal preference	
51.	Went up from one, went down from the other. Utilize one staircase for going up and the other for going down
52.	Curious, wanted to experience it
53.	Familiar
54.	For the sake of a change
55.	Saw it while navigating on the ground floor
56.	Wanted to walk-spend more time

Table 5
First visited room preferences on ground and first floors of Set 1 in the VE.

Gender	First Visited Room on Ground Floor Room 1 (123/132)	Room 2 (213/231)	Room 3 (312/321)	First Visited Room on First Floor Room 4 (45/465)	Room 5 (5)	Room 6 (645/65)
Female	25	1	19	19	2	24
Male	18	6	21	20	1	24
Total	43	7	40	39	3	48

Table 6
Staircase preferences for Set 1 and Set 2 in the VE.

Gender	Staircase Preferences for Set 1				Staircase Preferences for Set 2			
	A-A	A-B	B-A	B-B	A-A	A-C	C-A	C-C
Female	7	12	11	15	7	13	5	20
Male	4	10	8	23	18	10	7	10
Total	11	22	19	38	25	23	12	30

Table 7
First visited room preferences on ground and first floors of Set 2 in the VE.

Gender	First Visited Room on Ground Floor			First Visited Room on First Floor		
	Room 1 (123/132)	Room 2 (213/231)	Room 3 (312/321)	Room 4 (45/465)	Room 5 (5)	Room 6 (645/65)
Female	10	16	19	22	5	18
Male	7	11	27	24	10	11
Total	17	27	46	46	15	29

Table 8
Gender differences within each set.

	Set 1	Set 2	*Overall*
SOD	$F > M$	$F = M$	$F > M$
Sense of Presence	$F = M$	$F = M$	$F = M$
Comp. Fam.	$F > M$	$F = M$	$F > M$
Play Comp. Game	$F > M$	$F > M$	$F > M$
Comp. Game Usage	$F < M$	$F = M$	$F < M$
Play Comp. in Years	$F < M$	$F < M$	$F < M$
Play Shooting Games	$F > M$	$F > M$	$F > M$
1st Room - Ground	$F = M$	$F = M$	
1st Room - First	$F = M$	$F = M$	
Direction - Ground	$F = M$	$F = M$	
Direction - First	$F = M$	$F = M$	
Staircase - Ascend	$F = M$	$F = M$	
Staircase - Descend	$F = M$	$F > M$	
Nav. Total Duration	$F > M$	$F > M$	

For Set 2, more than half of the participants preferred to start at Room 3 on the ground floor and Room 4 on the first floor. In both cases, the majority of the genders preferred these rooms (see Table 7). More than half of the participants utilized the same staircase for ascending, descending; 30 participants utilized the Staircase C that was on the right of the entrance and 25 utilized the Staircase A that was on the left of the entrance (see Table 6). The participants indicated that 'distance', which is being close to the last visited room on the ground floor and 'personal preference', which is familiarity with the same staircase, determined their staircase preference.

Chi-square analysis indicated that there were no significant relationships between gender and the first visited rooms on the ground and first floors of Set 1. In addition, there were no significant relationships between gender and the first visited rooms on the ground and first floors of Set 2. A further analysis was conducted in order to see if there was a significant relationship between gender and the direction of navigation, in other words, did the participants continue their room visits in a clockwise or in an anti-clockwise manner for the ground and first floors of Set 1 and Set 2. Participants who navigated in a clockwise manner began at any room and then visited the other rooms in a clockwise manner, for example participants could visit the rooms as: Room 1 – Room 2 – Room 3, Room 2 – Room 3 – Room 1, Room 3 – Room 1 – Room 2 for the ground floor, and Room 4 – Room 5 and Room 6 – Room 4 – Room 5 for the first floor. This was the reverse for the anti-clockwise navigation. According to the chi-square analysis, there were no significant relationships between gender and the direction of the navigation for the ground and first floors of Set 1 and for the ground and first floors of Set 2.

There were no significant relationships between gender and staircase preferences for ascending in Set 1 and Set 2. There was no significant relationship between gender and staircase preferences for descending in Set 1. However, there was a significant relationship between gender and staircase preferences for descending in Set 2 ($\chi^2=7.76$, df = 1, $p \leq 0.005$). According to the independent *t*-test, the mean staircase preferences for descending of female participants ($M = 2.47$, SD = 0.89) was significantly higher ($t = 2.88$, df = 88, two-tailed $p \leq 0.005$) than that of male participants ($M = 1.89$, SD = 1.00).

In the virtual navigation total durations of Set 1 and Set 2, the mean score was 97.14 s (SD = 35.68) and the range was from 60 s to 231 s. The navigation durations were grouped into four categories as 60–72 s, 73–85 s, 86–106 s and 107–231 s. The 25th, 50th and 75th percentiles formed these categories.

In both sets, male participants completed the virtual navigation in a shorter period than female participants did. Chi-square analysis indicated that there were significant relationships between gender and the virtual navigation total durations for both Set 1 and Set 2 ($\chi^2=37.70$, df = 3, $p \leq 0.0001$and $\chi^2=35.16$, df = 3, $p \leq 0.0001$, respectively). In Set 1, the mean virtual navigation total durations of female participants ($M = 3.36$, SD = 0.91) was significantly higher ($t = 7.43$, df = 88, two-tailed $p \leq 0.0001$) than that of male participants ($M = 1.96$, SD = 0.88). Similarly, in Set 2, the mean virtual navigation total durations of female participants ($M = 3.07$, SD = 0.94) was significantly higher ($t = 7.44$, df = 88, two-tailed $p \leq 0.0001$) than that of male participants ($M = 1.73$, SD = 0.751). A summary of the gender differences within each set is depicted in Table 8.

3.3. Related to navigational abilities during the virtual navigation

Navigational abilities with respect to SOD, SOP, CF, frequency of playing computer games and playing computer games in years were examined between the staircase preferences for ascending and descending in each set. In Sets 1 and 2, there were no significant relationships between SOD and the staircase preferences for ascending and descending. There were no significant relationships between SOP and the staircase preferences for ascending and descending for Set 1 and 2. In addition, there were no significant relationships between CF and the staircase preferences for ascending and descending for both sets.

In Set 1, there was no significant relationship between frequency of playing computer games and the staircase preferences for ascending; however, there was a significant relationship between frequency of playing computer games and the staircase preferences for descending ($\chi^2 = 8.97$, df = 2, $p \leq 0.011$). In Set 2, there was no significant relationship between frequency of playing computer games and the staircase preferences for ascending and descending. Likewise, there was no significant relationship between playing computer games in years and the staircase preferences for ascending and descending for both sets.

ANOVA was conducted to find if the staircase preference for descending within the computer game usage had different means in Set 1. The effect of the computer game usage was significant overall ($F_{2,71}=4.90$, $p \leq 0.010$). When a Bonferroni adjustment was made for the number of comparisons, there were two significant differences. The mean of "once in a week" ($M = 1.86$, SD = 0.36) was significantly higher ($t = -2.58$, df = 42, two-tailed $p \leq 0.013$) than that of "less than

Table 9
Navigational abilities during the virtual navigation.

		Set 1	Set 2
SOD	Staircase - Ascend	GSOD = PSOD	GSOD = PSOD
	Staircase - Descend	GSOD = PSOD	GSOD = PSOD
SOP	Staircase - Ascend	GSOP = PSOP	GSOP = PSOP
	Staircase - Descend	GSOP = PSOP	GSOP = PSOP
Comp. Fam.	Staircase - Ascend	GCF = PCF	GCF = PCF
	Staircase - Descend	GCF = PCF	GCF = PCF
Comp. Usage	Staircase - Ascend	$R = O = F$	$R = O = F$
	Staircase - Descend	$O > R$, $F > R$	$R = O = F$
		* Rare, Once, Frequently	
Play Comp. in Years	Staircase - Ascend	No Relationship	No Relationship
	Staircase - Descend	No Relationship	No Relationship

once in a week" (M = 1.47, SD = 0.51). The mean of "more than once in a week" (M = 1.77, SD = 0.43) was significantly higher (t = −2.47, df = 58, two-tailed $p \leq 0.016$) than that of "less than once in a week" (M = 1.47, SD = 0.51). There was no significant difference between the means of "once in a week" and "more than once in a week". Table 9 depicts the results of the navigational abilities during the virtual navigation.

3.4. Related to the cue pairs with 90° and 180° differences

In order to test whether a 90° difference (Set 1) or a 180° difference (Set 2) between the cue pairs were efficient in the VE with respect to the first visited rooms on the ground and first floors, staircase preferences, virtual navigation total durations and SOP. Independent sample t-tests and bivariate correlation tests were conducted.

3.4.1. According to the first visited room

The mean of the first visited room on the ground floor in Set 2 (M = 2.32, SD = 0.78) was significantly higher (t = −2.72, df = 178, two-tailed $p \leq 0.007$) than that of Set 1 (M = 1.97, SD = 0.97). With respect to the correlation test, there was a low positive significant relationship between Set 1 and Set 2 in the circulation path of the ground floor with respect to the first visited room (r = 0.20, df = 178, $p < 0.007$). On the other hand, the mean of the first visited room on the first floor in Set 1 (M = 2.10, SD = 0.98) was significantly higher (t = 2.06, df = 178, two-tailed $p \leq 0.041$) than that of Set 2 (M = 1.81, SD = 0.90). With respect to the correlation test, there was a low negative significant relationship between Set 1 and Set 2 in the circulation path of the first floor with respect to the first visited room (r = −0.15, df = 178, $p < 0.041$).

3.4.2. According to the staircase preferences

According to the staircase preferences for ascending, the mean of the staircase preferences for ascending in Set 2 (M = 1.93, SD = 1.00) was significantly higher (t = −2.55, df = 178, two-tailed $p \leq 0.011$) than that of Set 1 (M = 1.63, SD = 0.49). With respect to the correlation test, there was a low positive significant relationship between Set 1 and Set 2 in the staircase preferences for ascending (r = 0.19, df = 178, $p < 0.011$). Likewise, the mean of the staircase preferences for descending in Set 2 (M = 2.18, SD = 0.99) was significantly higher (t = −4.42, df = 178, two-tailed $p \leq 0.0001$) than that of Set 1 (M = 1.67, SD = 0.47). The correlation test indicated that there was a low positive significant relationship between Set 1 and Set 2 in the staircase preferences for descending (r = 0.31, df = 178, $p < 0.0001$).

The independent t-test indicated that there was no significant difference between Set 1 and Set 2 with respect to the virtual navigation total durations. Table 10 depicts a summary of the cue pairs with respect to the first visited rooms on the ground and first floors, staircase preferences, virtual navigation total durations and SOP.

Table 10
Cue pairs with 90° and 180° differences.

1st Room - Ground	Set 1 < Set 2	Low (+) Correlation
1st Room - First	Set 1 > Set 2	Low (-) Correlation
Staircase - Ascend	Set 1 < Set 2	Low (+) Correlation
Staircase - Descend	Set 1 < Set 2	Low (+) Correlation
Nav. Total Duration	Set 1 = Set 2	

4. Discussion

Previous studies in literature related to staircases mainly focused either on the environmental features that affect staircase use (Olander, 2009; Nicoll, 2007), simulation systems that are based on evacuation of buildings using staircases (Sun, 2009) or causes for disorientation (Buechner, 2010; Hölscher et al., 2005; 2006; Passini, 1984). The present study aims to understand how staircases could be utilized during virtual navigation and how they affect vertical navigation in a novel multi-level desktop VE. As Riecke (2003) demonstrated, purely visual navigation is sufficient for basic navigation tasks in a VE. As there are various affordances in a VE, the staircase was considered as one of the important local architectural cues in a VE that afford access to different levels. With respect to the virtual navigation, it is hypothesized that there is a difference between ascending and descending staircase preferences of users in the VE. The ascending staircase preference for Set 1 and Set 2 are evaluated according to the first and last visited rooms on the ground floor (see Table 1). In Set 1, there was no significant difference between the staircases A and B, even though the participants stated Staircase B as the main staircase. However, according to the first visited room in Set 2, Staircase A was preferred more than Staircase C since the participants started their virtual navigation from Room 1 and finished at Room 3 (see Fig. 3a). This indicated that the participants utilized the staircase that they saw first while entering Room 1 in the VE; in other words, the 'view direction' attribute is influential in the staircase preference.

On the other hand, with respect to the last visited room of Set 2, Staircase C is utilized more than Staircase A for descending. Even though the distance from the staircase to the entrance/exit is kept constant, the distance from the staircase to the rooms varies; this caused the participants to prefer the closest staircase to the last visited room (see Table 1). As a result, 'distance' was a determining attribute for the staircase preference. One could have expected a similar difference in Set 1 since the staircases are positioned differently in the VE. The participants' preference differed according to the first and last visited rooms, when the angle between the cue pairs is greater than 90°. Another interesting finding is related to the participants' view directions; especially in Set 2, the participants utilized the staircases that are situated on the left side of their view directions. The tendency of people to do things from left to right be related to the individual's culturally determined writing and reading habits (De Agostini et al., 2010; Maass et al., 2007; 2009). Maass et al. (2007) claimed that the directional bias in an individual's perception is based on the writing and reading habits, in other words, exploring an environment in a specific direction is related to the directionality of writing and reading. Individuals explore an environment with a left to right trajectory and process the spatial information easier when they follow a left to right directionality (Maass et al., 2009).

Previous studies in gender (Barkley and Gabriel, 2007; Chai and Jacobs, 2009; Coluccia and Louse, 2004; Picucci et al., 2011; Tlauka et al., 2005) indicated that females tend to refer to landmarks more often than men; in other words, females use landmark information to find their way in new environments, whereas males tend to use both geometric and landmark information. In addition, it was found that females rely more on landmarks and have better object memory than males in remembering the location and identity of 2D objects (Barkley and Gabriel, 2007; Levy et al., 2005; Voyer et al., 2007). It is hypothesized that there is a relationship between gender and staircase preferences in the VE and females prefer the staircase that they see first in the desktop VE during the virtual navigation. However, no relationship was determined between genders and in staircase preference for either ascending in Set 1 and Set 2, and descending in Set 1. In line with Iachini et al. (2005), there was no gender difference in object recognition in a real 3D environment. The only relationship between gender and the descending staircase was found as the Staircase A in Set 2 (see Table 8), which was located on the right side of the last visited room on the first floor, was in favor of females (see Fig. 3b). This could indicate that when two cues are in equal distance and are opposite to each other, females are more orientated than males to the cue on the right side. Alexander et al. (2002) showed that females have a better memory for object locations in the right visual field. Likewise, De Goede (2009) found that object-identity memory and object-location memory were better retrieved when located in the right visual field; however, they did not note a gender difference. The visibility of the staircases from the rooms could be a factor that could affect the participants' memory of the cues; however, further research has to be conducted to elaborate the tendency of females towards the right side and the visibility of the cues.

Sholl et al. (2000) indicated that people with a GSOD actively explore and focus on details in new environments and they remember new routes, whereas participants with a PSOD worry about getting lost, feel more anxious and more likely to lose their way (Hartley et al., 2003; Hund and Nazarczuk, 2009; Hund and Padgitt, 2010; Padgitt and Hund, 2012). With respect to Sholl et al. (2000) findings, in this study, it is hypothesized that there is a relationship between SOD and staircase preference of the participants. The participants with a GSOD would utilize different staircases in the two sets, since they are able to explore and attend to different cues in the VE while the participants with a PSOD would prefer the same staircase for ascending and descending. However, the results indicated that there is no relationship between SOD and staircase preference in the VE and the participants with a PSOD do not prefer a specific staircase during the virtual navigation (see Table 9). This might be related to the clear visibility of the staircases and less complexity of the environment. Both staircases for ascending and descending were visible to the participants when they left the last room, so the participants with a PSOD did not have to worry about getting lost. If the environment consisted of more details and cues, there might have been a difference in staircase preference between the participants with GSOD and PSOD.

Even though various studies showed that as the experience with computer increases there is a better performance in visual search (Dye et al., 2009b) and visual memory (Ferguson et al., 2008), an increase in visual attention (Castel et al., 2005; Green and Bavelier, 2003; 2006; Spence et al., 2009), and leads to lower levels of computer anxiety (Bonzionelos, 2004; Tekinarslan, 2008). The present study revealed no relationships between the staircase preferences and CF, as well as between the staircase preferences and CE (see Table 9). It was hypothesized that the participants with a GCF and with a high CE would prefer different staircases for ascending and descending, whereas the participants with a PCF and low CE would prefer the same staircase for ascending and descending. The reason for this indifference might be due to the similar CEs of the participants. The participants are familiar with the computer since they used it more than once a week. In addition, they had the same educational background and they are familiar with computer-based environments due to the compulsory computer-based courses that they took during the second and third years of their education.

Since the staircase locations were different in the two VEs, there were significant differences between Set 1 and Set 2 with respect to the first visited rooms on the ground and first floors, and the staircase preferences for ascending and descending (see Table 9). Set 2 was in favor with respect to the first visited room on the ground floor of the VE. All of the rooms were visible when the participant entered the VE, since there was no staircase in the middle that interfered with the view of the participants in Set 2. During the virtual navigation, some participants indicated that they did not notice Room 2, which was directly across the entrance in Set 1 due to the staircase in the middle (see Fig. 2a). With respect to the first visited room on the first floor, Set 1 was in favor. According to the staircase preferences for ascending and descending, Set 2 was in favor. Both staircases were located along the sidewalls that enabled the participants to see easily them from the rooms (see Fig. 3). There was no difference between Set 1 and Set 2 with respect to the virtual navigation total durations and presence. Although in Set 1, there was a staircase in the middle (Staircase B) that interferes with the virtual navigation, the results indicated no difference. In addition, since the two VEs were the same except for the locations of the staircases, the presence levels were indifferent.

5. Conclusion

A staircase is an important local architectural cue that provides access to different levels in a building. As Hölscher et al. (2006) stated the position of the staircase has to be designed accordingly with the individual's activity within the building. However, individuals can lose their orientation during vertical travel. In order to understand the role of staircases in a novel multi-level desktop VE, a model was formulated that integrated gender, navigational abilities and the geometric attributes of the staircase during navigation.

In the present research, two VEs were provided with the angle between the cue pairs from the observation point as either 90° or 180°. According to the findings of the study, a 90° difference between the cue pairs did not have an effect on the staircase preferences; however, in a 180° difference, staircase preferences differed according to the order of the visited rooms during virtual navigation. There was no gender difference between the staircase preferences with a 90° and 180° difference, except for Staircase A in the cue pair with a 180° difference, which was utilized more for descending by females. Further analysis needs to be conducted in order to understand the tendency of females in preference of cues on their right side. Individual's navigation abilities with respect to the SOD, CF and CE did not have an effect on the staircases preferences within the two VEs. The cue pair with an angle difference of 180° was preferred more during ascending and descending. The findings suggest that individuals can perceive action possibilities of an environment through purposefully designed cues. This suggests that designers can increase individuals' perceptions of action possibilities through the usage of different cues. This study provides an understanding on the position of the staircases with respect to the entrance and the rooms, and the individual's activity within the building. This can shed light on the design and position of staircases within VEs and real environments such as hospitals, shopping malls, universities and large complexes.

Based on this study, the following interior design heuristics are suggested:

1 Locate staircases so that they are visible from where people are located in the building.
2 Locate staircases according to the individual's circulation path. For easy access to the lower or upper floors, locate staircases in close proximity to the last visited area. For exploration of the building, locate staircases in close proximity to the entrance.
3 To emphasize a certain staircase, locate that staircase within the central area of the building and make it visible either from the entrance or from the last visited area in the building.
4 In novel buildings, in which the individual has no prior knowledge about the building, individuals prefer the same staircase that they utilized for ascending and descending. Make the staircase accessible and visible; enable direct visual communication.
5 Orient the first steps of the staircases so that the individuals require less turns in order to enter the staircase from the entrance or from

the last visited areas in the building.

6 Depending on the culture, an individual's exploration of an environment starts from the left and finishes on the right. Locate cues according to the individual's circulation path. To emphasize a certain cue, locate it at the beginning or at the end.
7 Locate cues related to females in the right visual field of the building in order for them to remember for future use.
8 To provide different utilizations of staircase pairs in buildings with more than one staircase, locate the staircase pairs further about from each other with an angle difference of more than 90°.
9 To provide equal utilizations of staircase pairs in buildings with more than one staircase, locate the staircase pairs at a 90° difference from the observation point.

Since spatial memories for VEs are organized similarly to memories of real environments, human response to any environment occur in an analogous way. The findings of the present study constitute a theoretical improvement for the human-computer interaction literature. In the VE with a 180° difference between the cue pairs, a relationship was found between the ascending and descending navigation routes. Further analysis indicated that the vertical navigation route preference at the starting level was either related to the first or last cues stored in the memory. Therefore, VE designed on this evidence holds numerous advantages for studying human-computer interaction in studying novel environments at any scale from a building to city size environments.

For further research, the form of the staircases and the visibility of the staircases can be varied by having circulation paths i.e. corridors or hallways that lead to the staircases, and placing staircases at different angles other than 90° and 180°. The design of the VE can be elaborated by having more floors for vertical travel, more rooms to visit and an asymmetrical spatial organization since the present VE was symmetrical. The VE could constitute a function, like a hospital, shopping mall or university. The effects of different local architectural cues for vertical navigation could be investigated. A comparison between left-handed and right-handed participants could be done in order to understand the effects of handedness on the staircases during vertical navigation. The staircase preferences of individuals from different age groups and with different educational backgrounds could be investigated.

Declaration of Competing Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property. We further confirm that any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript. We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). She is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author and which has been configured to accept email from ipek.memikoglu@atilim.edu.tr.

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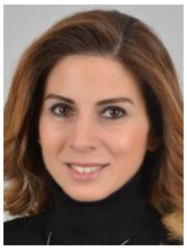

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