The Optimal D:H Ratio Assessment for Sense of Enclosure in Virtual Landscapes

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Abstract: Virtual landscape is going through an advancement initiated by the development of digital technologies related to virtual environments. The virtual landscape has been used as a tool to develop the real world; however, this domain itself also carries a design value. Taking advantage of the unique affordances of such environments, virtual landscape designers need to increase users' sensory, perceptual, and attention abilities to allow cognitive relationships by implementing the theories of the physical world. This research adopts the D:H ratio principle to understand its optimal suggested values in the real world to assess the sense of enclosure in virtual landscapes. The statistical analysis of the results indicate that the optimal D:H ratios for "Open" and "Comfort" qualities of space are larger in the virtual landscape than in real-world suggestions. The perception of "Constricted" and "Human-scale" qualities in the virtual landscape is perceived differently depending on the surrounding building heights. By focusing on the D:H Ratio principle, the research results suggest that virtual landscapes fed by design disciplines such as urban planning, landscape architecture, and architecture produce a more compact and holistic perspective by increasing the user-space interaction.

Keywords: Virtual landscape, D:H ratio, metaverse, sense of enclosure, spatial perception

1 Introduction

Virtual worlds allow socialization by their nature (BOELLSTORFF 2015). Hence, while the development of 3D graphics has created space that benefits from real space, increasing the level of graphical realism in the virtual world allows social and spatial interactions to happen (LUDLOW & WALLACE 2007). Additionally, a virtual landscape is an immersive three-dimensional digital environment going beyond physical reality with the concept of Metaverse. SMART et al. (2007) presented it as simulation technologies that virtually augment physical reality. The interactions between real space and virtual landscape show that virtual landscape has been used as a tool to develop the real world. However, as KIM et al. (2018) mentioned, virtual landscape carries value as a design domain. Nevertheless, current virtual landscapes cannot deliver quality space without a fixed design methodology, and virtual landscape design consumes a lot of time and can be an inefficient design process. Hence, it will be helpful if virtual landscape designers adopt the existing methodologies from real space landscape architecture to virtual landscape design. Instead of duplicating all physical world elements, focusing only on those that allow interactions in the virtual landscapes, and inserting real-world perception in these spaces will offer a potential design method (LIFTON & PARADISO 2009). This research suggests that it is important to examine and estimate the critical differences by assessing the virtual landscape's limitations and the real world.

In landscape architecture, architecture, and urban planning areas, many scholars have proposed various design techniques to create expressive and impressive environments in the real world. ALEXANDER'S A Pattern Language (1977) and LYNCH'S Good City Form (1984) combined controlled experiments with case studies. They provided a guideline for defining and

Journal of Digital Landscape Architecture, 7-2022, pp. 425-434. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-724-3, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537724041.

evaluating the urban space and designated physical characteristics that contribute to the design approach. This process has accelerated with the expansion of digital technologies used in various fields. The use of visualization technologies as a tool has allowed the emergence of new methods for investigating urban space in the real world. Numerous researchers have used 2D visualization methods of urban spaces, such as sketches, scale models, or computer simulations, to analyze participants' perceptions (EWING et al. 2013). For instance, NASAR (1984) evaluated visual preferences in urban street scenes using videotapes and slides. IM (1987) used computer graphic simulations to assess the effectiveness of urban design qualities in urban public courtyards. As can be seen, numerous studies have used virtual landscape as a tool to produce design approaches in the real world, but these studies often focus too much on "reality" and "scenic quality." Therefore, it has been observed that a lack of research exists regarding the spatial perception of urban public spaces in the virtual landscape.

This research chose the D:H ratio principle as the urban design principle for testing. IM (1987) states that visual perception of an environment is related to the spatial D:H ratio. Hence, numerous urban design theorists consider the D:H ratio ("D" represents the depth or width of open space and "H" represents the height of its surrounding buildings.) as a critical urban design principle to indicate the sense of enclosure. Therefore, this research adopted various D:H ratio theories and guidelines on virtual landscapes to evaluate multiple design criteria and improve measurable techniques. For this reason, this research aims to understand whether it is possible to apply the D:H ratio theories, which is a valuable design principle for urban enclosed spaces in the real world, to virtual landscape design. By examining the relationship of the D: H ratio, an assessment to indicate users' spatial perceptions in virtual landscapes is proposed in this research. A survey data analysis is presented to evaluate perceptual qualities to improve user-space interaction in the virtual landscape design. The survey's main purpose is to investigate whether we understand the virtual landscape the same as the real environment and, if not, how it affects our judgment. The findings of this research will be helpful for landscape architects to understand the spatial and perceptual characteristics of the virtual landscape and expand their research territory.

2 Literature Review

Human-space interactions, communication, and spatial features provide a research area for long-term social sustainability and thus the settlement of urban components and vice versa (SATIROGLU 2016). Therefore, an individual's perception of an enclosed space can be influenced by other factors such as architectural designs, the content of surrounding building facades, or its dimensions. Numerous urban theorists and designers have evaluated urban squares and presented qualities that vary according to the pedestrian's experience, psychology, and perception. Taking advantage of such relationships' unique affordances for allowing the spatial interaction constructions, urban squares with proper D:H ratios, have important design value to create a "sense of enclosure" for an open space in a city (COLLINS et al. 2006, HANDY et al. 2002, TRANCIK 1986, JACOBS 1993). ALEXANDER et al. (1977) claimed that D:H ratios for streets should be less than 1:1 to achieve a sufficient balance between buildings' height and distance of the viewer from them. LYNCH (1984) suggested that the D:H ratios are between 2:1 and 3:1 for an optimal enclosure in urban squares. SPREIREGEN (1981) measured the ratio between "building facade height" and "frontal field of view width" in his study. He argued the sense different ratios provide as the sense of full enclosure for 1:1, threshold enclosure for 1:2, minimum enclosure for 1:3, and finally, enclosure loss for 1:4. The D:H ratio principle is widely used in practice and research, however, the challenges to test the theories and lack of sufficient objective evidence make it difficult to understand the ideal D:H ratio.

Visual-aided and computer-aided designs are also being used to understand the optimal D:H ratio. With an experiment conducted with university students and visitors using a photographic evaluation approach, Im (1983) suggested the optimal D:H ratio is 6.67 for the courtyards surrounded by the dormitory buildings in real space. More recently, Kim and Kim (2019) conducted an experiment to test the D:H ratio principle with VR. They proposed an optimal D:H ratio for the real world, focusing on the perceptual qualities of an enclosed urban square and the social activities that can be performed in it. Using VR techniques can provide an advantage by increasing the perception of "realism" over 2D visualization or 3D modeling techniques. As players interact with the virtual landscape in digital games, spatial features channel and impede players. Hence, to create a virtual landscape with higher quality, various types of resources, such as the spatial and cognitive components, need to be considered (Kim et al. 2018). Therefore, the experience equivalence between virtual and physical worlds needs to be maintained in order to keep the spatial reality perception at the optimal level. For example, in the game The Witcher 3: Wild Hunt (2015), it is possible to observe the attempt to keep the ratio in the space, but the ratio is not consistent (Figure 1).

Fig. 1: Sample of the D:H ratio in a digital game (The Witcher 3: Wild Hunt, 2015)

The width of the street and the height of the surrounding buildings are disproportionate; therefore, it is difficult to perceive the height of the players and NPCs. Considering the D:H ratio, the extent to which players perceive the space in various qualities, may allow for quality and coherent space design beyond the physical reality provided by the game.

3 Data Collection and Methodology

This research conducted a survey in two phases to gather required data for obtaining statistically measurable results. The methodology of this research used 6 different virtual landscapes modelled with Unreal Engine 4 to test research question by allowing the participants to freely wander around and observe the environments (Figure 2). Moreover, it regarded the optimal D:H ratios offered by numerous urban theorists given above for the real world in the design of the experimental environments. Hence, in the design stage of these virtual landscapes, the researchers applied 1:1, 2:1, 3:1, 4:1, 5:1, and 6:1 D:H ratios on all of the environments.

3.1 Test Environment Design

GEHL (2010) states that people can feel and sense the environment in an enclosed urban space up to 35 meters far and the optimal distance allowing visual perception is 60-70 meters. Therefore, the virtual landscapes area was designed as 40×40 m allowing the space's visual perception to be considered as an independent variable. The avatar uses the first-person perspective and the eye level was determined by considering the average male height in the tested area (Average male height 176.0 cm). This research did not consider facade (surrounding buildings) design as an independent variable; therefore, the facade was modelled as white walls. Thus, the focus was on the participants' ratio perception of depth and height rather than the function of the enclosed space and the social activities that can be performed. The participants used their avatars to walk around freely and explore the environment. This research carried out two experiments, six distinctive groups of participants took part in a way that three groups joined experiment A and the other three groups joined experiment B. The reason for conducting two different experiments was to avoid affecting participant's judgment as the scope and scale of the display may have influenced their perception. In experiment A, the beam projector was used to understand the scale and scope of the designed areas. Participants sat 4 meters away from the 2 meters projector screen in a room and navigated the area projected on the screen with the keyboard and mouse. Experiment B was conducted on a standard-size portable computer (15.6 inches) to understand participants' perceptions better. The

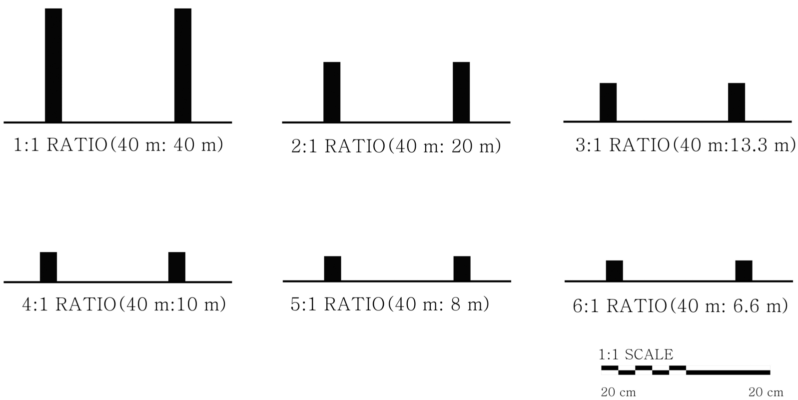

Fig. 2: Sectional representations of the designed areas

viewing distance of the monitor screen of the participants was calculated as approximately 80-100 cm. Group 1 tested 1:1, 2:1, 4:1, 5:1 and 6:1 ratio; group 2 tested 1:1, 3:1, 4:1, 5:1 and 6:1 ratios and group 3 tested 2:1 and 3:1 ratio. A total of 92 participants joined the experiment. Participants were recruited via undergraduate and postgraduate university mailing lists, public areas in the campus, and public social networks in the university groups.

The experimental phase of the research took three weeks to be completed. After arranging the required equipment, such as a display, the researchers briefly explained the survey's purpose and procedure to the participants. In the first phase of the experiment, this research built a Google Form questionnaire to collect control variables, including basic socio-demographic variables, such as gender, age, and education. Also, due to the lack of available standard tools to evaluate participants' virtual landscape expertise, questions about their familiarity with the virtual landscape design were asked as control variables to understand users' experience. Additionally, the qualities of the designed spaces were evaluated as dependent variables.

In the second phase of the experiment, the questions were about the D:H ratio of the designed environment. Since the experiment focused on the influence of D:H ratios on the perceived qualities of urban enclosed spaces, the D:H ratios were set as independent variables. The sense of enclosure was examined regarding four dependent variables in the virtual landscape: open, comfort, constricted, and human-scale. The results were compared with the 2:1 and 3:1 ratios as LYNCH (1984) claimed to be the optimal in the real world. The researchers compared each dependent variable to understand whether real-world D:H ratio theories can be applied to the virtual landscape. A total of seven questions were asked about the perceptual quality of the area, such as “I feel captivated and constricted in this space.”, “I feel comfortable and cozy in this space.”. The answers were given on a Likert scale: (The participants were first informed that “1” for “strongly disagree,” “5” for “strongly agree”), open-ended, and multiple choice. Thus, using SPSS (Statistical Data Analysis Program), the Mean and Standard Deviation for each ratio were presented and compared with each other.

4 Results

4.1 Descriptive Statistics for Control Variables

The research consisted of the statistical analysis of 373 recordings in total for two different experiments conducted with six different groups in the survey [Beam Projector: (16x5) + (16x5) + (13x2), Monitor: (16x5) + (15x5) + (16x2)]. The frequency statistics of control variables were evaluated for each.

The experiment evaluated the participant's familiarity with the virtual environment based on the questionnaire's responses. It was assessed that 25.0% of the participants stated they had not wander in a virtual landscape before, while 75.0% of the participants declared that they had. The participants were asked to indicate the activities they performed in the virtual environment, and, digital game playing was observed as the most performed activity with 42.4%. The participants were asked how many hours a week they played digital games on average. While 27.2% of the participants claimed that they do not play digital games at all. On the other hand, 60.9% of participants claimed to have played between 1-10 hours a week. The rest with 12% between selected 11-20 hours. The research concluded that they played mostly MMORPG with 54.3%. In addition, it was evaluated that the participants were average-below familiar with virtual landscape design with a score of 2.66, also they were at an average familiarity level with the digital game concept with a score of 3.03.

4.2 Descriptive Statistics Analysis of Experiment A

Figure 3 was given as an example to show the relationship between D:H ratios and the four dependent variables. The first group (Group A-1) gave the highest score of 6:1 (M = 4.00, Std = 1.095) for open, 4:1 (M = 3.38, Std = 0.957) for comfort, 1:1 (M = 4.25, Std = 1.342) for constricted, and 1:1 (M = 4.25, Std = 1.000) for the human-scale, where they felt small in space. The results show that the constricted and human-scale variables are inversely proportional to the heights of the surrounding buildings, with some exceptions (constricted). It was observed that the highest scores given for open and comfort were the 6:1 and 5:1 ratios respectively. Hence, the suggested ratios for these qualities in the real world are higher in the virtual landscape.

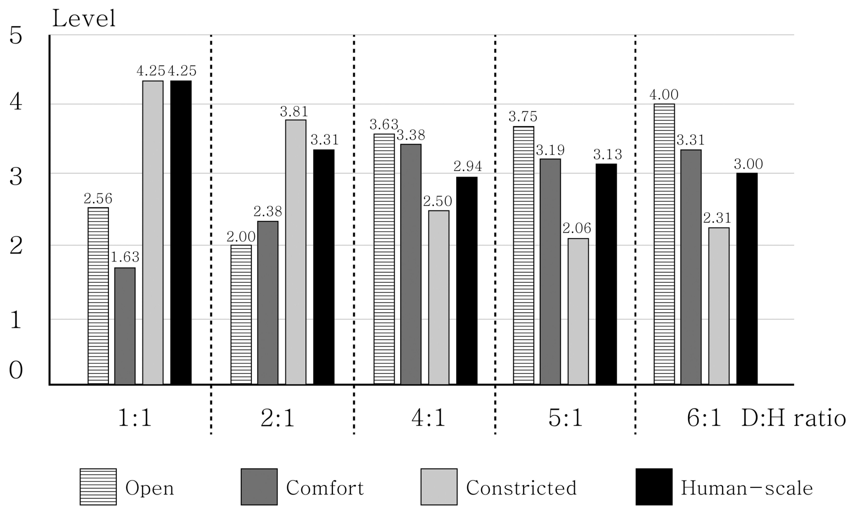

Fig. 3: The relationship between D:H ratios and the four dependent variables (Group A-1)

The second group's (Group A-2) results show that the constricted and human-scale variables are inversely proportional to the heights of the surrounding buildings, with no exceptions. Therefore, the author compared two dependent variables (openness and comfort) to understand if the real-world D:H ratio theories apply to the virtual landscape. It was observed that the highest scores given for openness and comfort were 5:1. Hence, the suggested ratios for these qualities in the real world are higher in the virtual landscape.

For the third group (Group A-3), it was observed that even though the surrounding buildings' height was lower in the 3:1 ratio, the participants had a higher score of a sense of constriction. However, participants felt a sense of smallness with a higher score in the 2:1 ratio where the surrounding building height was higher.

4.3 Descriptive Statistics Analysis of Experiment B

Figure 4 was given as an example of the relationship between D:H ratios and the four dependent variables. The first group (Group B-1) gave the highest score of 4:1 (M = 4.56, Std = 0.727) for open, 5:1 (M = 3.75, Std = 0.775) for comfort, 2:1 (M = 3.69, Std = 1.078) for constricted, and 1:1 (M = 3.44, Std = 1.315) for the human-scale, where they felt small in space. It was observed that the highest scores given for openness and comfort were the 4:1 and 5:1 ratios respectively. Hence, the suggested ratios for these qualities in the real world are higher in the virtual landscape. The results show that the constricted and human-scale variables are inversely proportional to the heights of the surrounding buildings, with no exceptions.

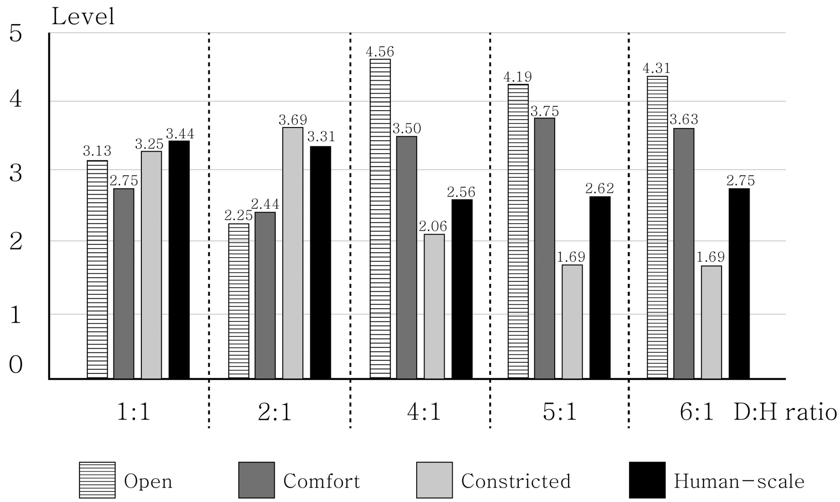

Fig. 4: The relationship between D:H ratios and the four dependent variables (Group B-1)

In the second group (Group B-2), the highest scores given for openness and comfort were 5:1 and 5:1 ratio, respectively. Hence, the suggested ratios for these qualities in the real world are higher in the virtual landscape. The results show that the human-scale variable is inversely proportional to the heights of the surrounding buildings, with no exceptions. However, participants felt constricted with a higher score in the 2:1 ratio, where the surrounding building height is lower compared to the 1:1 ratio.

The third group's (Group B-3) results show that participants had a higher score regarding the sense of constriction and smallness where the surrounding buildings' height was higher. The highest scores given by each group to the dependent variables were summarized in Table 1.

This research was evaluated urban public space qualities according to various devices and couldn't reach any specific pattern. However, users' perceptual differences can be seen.

Table 1: Summary of the ratios with each group's highest scores for four dependent variables

Groups	Open	Comfort	Constricted	Human Scale
Group A-1	6:1 ratio (4.00)	4:1 ratio (3.38)	1:1 ratio (4.25)	1:1 ratio (3.17)
Group A-2	5:1 ratio (3.75)	5:1 ratio (3.44)	1:1 ratio (4.63)	1:1 ratio (4.56)
Group A-3	3:1 ratio (3.38)	2:1 ratio (2.85)	3:1 ratio (3.08)	2:1 ratio (3.54)
Group B-1	4:1 ratio (4.56)	5:1 ratio (3.75)	2:1 ratio (3.69)	1:1 ratio (3.44)
Group B-2	5:1 ratio (4.40)	5:1 ratio (3.73)	1:1 ratio (4.67)	1:1 ratio (4.13)
Group B-3	2:1 ratio (4.06)	3:1 ratio (3.19)	2:1 ratio (2.75)	2:1 ratio (3.00)

5 Discussion

While the research analyses whether the 2:1 and 3:1 ratios recommended by LYNCH (1984) as optimal for urban enclosed space in the real world are applicable in the virtual landscape as well with four dependent variables; the discussion section focuses on (1) the possible reasons for the discrepancy between the theoretical optimal D:H ratios in the real world and the ratios observed in the experiment, and (2) on possible reasons for the different results of the various displays used in the experiment for the four dependent variables.

Regarding the first issue, Table 1 shows the examined scores in the experiment results for open and comfort, the observed ratios in virtual landscapes were evaluated higher than the theoretical optimal D:H ratios suggested by influential urban theorists, including LYNCH (1984). However, for constriction and human-scale, the observed ratios in virtual landscapes were lower than the optimal D:H ratios suggested in the real world. Although the optimal constriction and human-scale ratios have been suggested as 2:1 and 3:1 in the real world, this research evaluated the highest-score ratios given by participants for constriction and human-scale rather than the optimal ratio. People may perceive the sense of constriction and human scale of the squares in a different way than they perceive the other qualities of the squares. Numerous architectural variables or characters may express symbolic meaning (LANG 1987). Therefore, the empty white walls on the facade of the buildings in the designed environments may not match the environmental, aesthetic perceptions in the real world (RAPOPORT 2016).

Regarding the second issue, it was examined that the display used affects the visual perceptions of the participants differently. While the beam projector offers a wider visualization and navigation with its scale and scope, it was limited on the monitor screen. Here, it can be seen that the D:H ratio in the virtual landscapes may vary depending on users' perceptions and their familiarity with the virtuality.

6 Conclusion and Outlook

Virtual landscapes cannot provide the type of real-world urban public space qualities to increase the users' perception unless designers plan and provide them. Therefore, investigating the cognitive process of users in the environment, they are in plays a guiding role. Accordingly, to function successfully and efficiently in a virtual landscape, designers must ensure the optimal D:H ratio. The analysis suggested that D:H ratios for open and comfort qualities were scored higher than the optimal ratios suggested in the real world. In addition, it has been observed that the perceptions of constricted and human-scale qualities differ depending on the height of the surrounding buildings.

The expected academic value of the research is to propose more efficient and effective design techniques for virtual landscapes by feeding on design disciplines such as urban planning, landscape architecture, and architecture. Furthermore, for the industrial level, by focusing on the D:H ratio in a virtual landscape, designers in the field will be able to produce a more compact and holistic perspective that enhances user-space interaction. This research suggests that the D:H ratio can initiate a series of studies. As the research indicates, we can easily assume that in the near future, metaverse and any virtual landscape-related content such as digital games will aim to increase the spatial and visual perception of users with the benefits from the landscape architecture domain, and we need to prepare for it.

For future research, we are investigating how the dynamics of camera location can affect the ratio effect in the virtual landscape. Not only the first-eye view, but many digital games are currently presenting virtual landscapes with different camera locations, such as the quarter view angle. If we could verify the effectiveness of the ratio in those various camera angles, we will be able to provide stronger navigation to any landscape architect willing to join this new industry.

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