CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

AN EXPERIENCE-BASED SPATIAL DESIGN FRAMEWORK USING VR TECHNOLOGY: A CASE STUDY OF DESIGNING AN OFFICE LAYOUT

Wong, M. O. [1], Du, J. [1], Liang, H. Y. [1], Zhang, Z. Q. [1], Zheng, Z. J. [1], Zhou, S. H. [1], Feng, Q. [1] and Lee, S. H.[1,2]
[1] Department of Civil Engineering, The University of Hong Kong, Hong Kong, China
[2] shlee1@hku.hk

Abstract: Office layout design has a significant impact on the communication, concentration, and collaboration of workers, which contribute towards the overall productivity. Two-dimensional (2D) drawings with relevant renderings are commonly used as a traditional approach by architects to demonstrate spatial design plans to clients. However, the limited information provided by the 2D drawings may cause clients to misunderstand the spatial relationships and further make a wrong assessment. To address this issue, Virtual Reality (VR) technology is identified as a potential solution in virtue of its capabilities for the immersive experience and interactive design. This research then proposes an experience-based spatial design framework using VR technology, which aims to enhance the 3D visualization and participatory evaluation during the conceptual design phase. In addition, the proposed framework is able to imitate the real-life activities in the VR environment, such as finding a seat, working with computers, and communicating with co-workers, to help clients evaluate different design plans interactively. In this research, a case study of designing spatial layouts of a research student center (RSC) is conducted to implement the proposed framework. Three different spatial design plans of the RSC are developed and presented to the students in the virtual environment. To evaluate the effectiveness of the proposed framework, this research carries out a comparative experiment to compare it with the traditional approach. It is believed that this framework can promote better user experience and higher clients' participation.

1 INTRODUCTION AND LITERATURE REVIEW

Office layout design has experienced a remarkable evolution from a cellular office to a cubicle then to an open-plan workspace (Walsh 2015), aiming to provide a satisfactory environment and further improve the overall productivity. However, it is still a challenge to understand clients' actual needs and balance different design principles since traditional design tools cannot support effective information-exchange between architects and clients. In addition, a questionnaire survey among officers indicated that officers would like to be involved when planning their office spaces (Kok et al. 2015). In order to have better user experiences and encourage clients' participation, VR technology can be used to supplement the traditional approach.

Previous research has suggested that VR technology can be of great help in the phase of conceptual design. Firstly, VR can support stronger understanding through immersive experience and assist users in the decision-making process by offering the abilities to view objects at true scale in believable environments (Berg and Vance 2017). Secondly, VR offers enhanced interaction capabilities compared to regular computer workspaces, which further offers a higher degree of freedom and a better way for expression to the users (Adenauer, Israel, and Stark 2013). Thirdly, a VR environment can be adopted to design, evaluate and test concepts and further replace physical mock-ups to reduce time and cost (Pungotra 2012). Besides, several studies have explored the utilization of VR technology in designing workspace layouts. Shiratuddin and Thabet (2002) have established a virtual-environment-based walkthrough application to enhance interaction and immersive experience during office design and construction phases. Davies (2004) has developed a PC-based virtual reality tool to engage all stakeholders into the participatory design of work environments by offering interactive design, active and realistic environments, unlimited viewpoints and direct control. Budziszewski et al. (2011) have created a software application called Troll to design workplaces for workers with motion disability and further analyzed the maximal arm reach and accessible working area by using computer simulation and VR techniques. These examples have shown the potential of applying VR technology for workspace design.

However, previous research mainly focuses on spatial exploration and design functions development while the relationship between architectural design principles and human behavior are rarely studied. Therefore, this research aims to propose an experience-based spatial design framework using VR technology to fill the gap. The objectives of this research are then clarified as: 1) to provide full-scale immersive experiences to supplement traditional approaches; 2) to develop interactive tasks to assist in clients' evaluation; and 3) to develop several office design plans for examining the design principles behind them with the actual human behaviors. It is believed that the proposed framework can effectively improve the design practice by enhancing spatial cognition and supporting clients' participation.

2 METHODOLOGY

In this research, the proposed design framework can be divided into the following steps as described in figure 1.

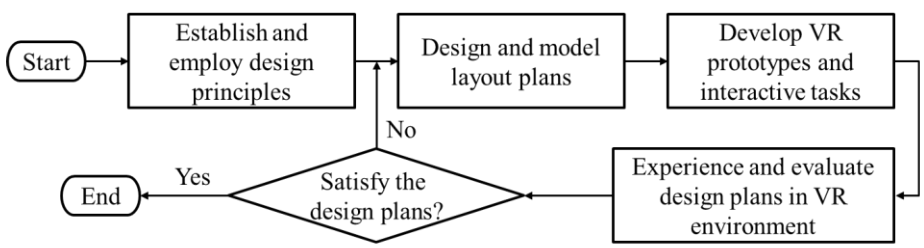

Figure 1: Flowchart of the VR-based design framework

Firstly, relevant design principles are established and employed according to space characteristics and clients' needs. Secondly, several layout design plans are created based on the design principles and restraints. These design plans are then constructed as 3D BIM models, which can be further refined and transformed in order to improve the rendering quality and ensure the model compatibility. Thirdly, the revised models are imported into a game engine where VR realization can be achieved by using relevant plugins. In addition, interactive tasks are designed and developed to assist in user experience and design evaluation. Eventually, the VR prototypes are executed and presented to clients for further assessment and revision until they are satisfactory. To validate the feasibility of this proposed framework, a case study is conducted step by step as shown in Section 3.

3 CASE STUDY

In this case study, the ground floor of the Research Student Centre (RSC) in The University of Hong Kong (HKU) is selected as the trial place where it serves as an office for student researchers to conduct their studies.

3.1 Design principles establishment

Initially, RSC is designed as an open-plan office equipped with low partitions and private discussion rooms (figure 2 and 3), which aims to promote a new culture for interdisciplinary practice and innovation (HKU 2016). However, after soliciting opinions from current users, individual privacy turned out to be an urgent concern that the students want to be addressed. Student researchers in RSC complained that they feel uncomfortable to be glanced by neighbors or people passing by. This problem of privacy may have a negative effect on work efficiency enhancement (Sundstrom, Herbert, and Brown 1982). Therefore, there is a need to propose new design plans that balance privacy and social interaction. Several measures learned from previous research, such as changing the type of enclosure, the height of partitions, and the degree of transparency of partitions, are adopted to develop new design plans (Lee 2010). In addition, to ensure the redesigned layouts possess similar capacities of accommodation and communication, the number of office furniture and area of discussion space should not be changed dramatically. As a result, two novel office plans are then designed in accordance with the design principles and restraints.

3.2 Office layout design and modeling

The first redesigned plan is called a privacy-oriented plan, which aims to directly enhance individual privacy protection and to further decrease distractions. In this plan, partitions are changed from 1.1 m to 1.5 m while other settings remain as original ones. Figure 4 and 6 respectively show the interior decoration and the floor plan of the BIM model of this plan. The second redesigned plan, namely an enclosed intradepartmental-shared plan, possesses five separated shared offices for student researchers from five departments to work with others in the same departments. Besides, the discussion spaces are further devised as an open discussion area and placed outside the enclosed offices. Due to space limitation, 103 sets of office furniture and 3 discussion tables are remained in this plan. The overarching principles of this plan are to protect inter-departmental privacy and to facilitate intra-departmental communication. Figure 5 and 7 respectively show the interior decoration and floor plan of the BIM model of this plan. Overall, the characteristics of the original plan and two redesigned plans are summarized in table 1.

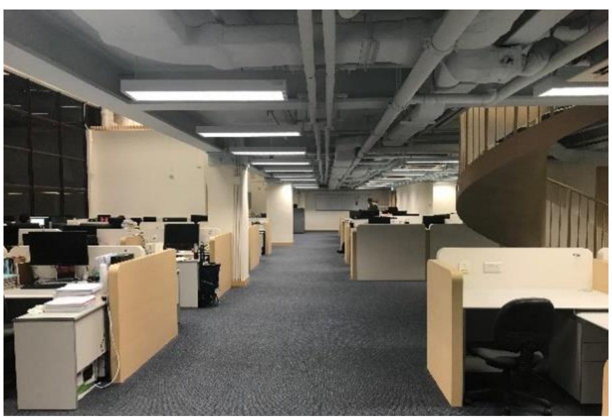

Figure 2: Interior decoration of RSC

Figure 3: BIM model of the original plan

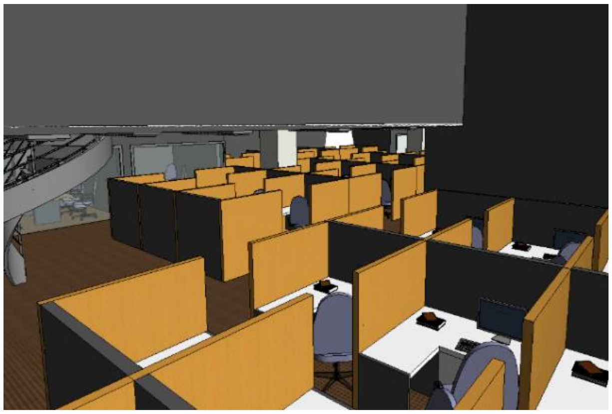

Figure 4: BIM model of the privacy-oriented plan

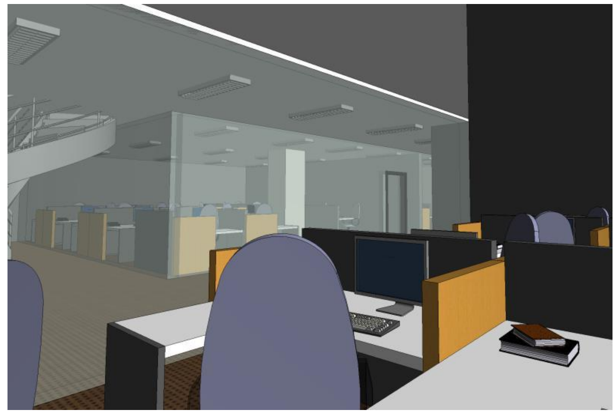

Figure 5: BIM model of the enclosed intradepartmental-shared plan

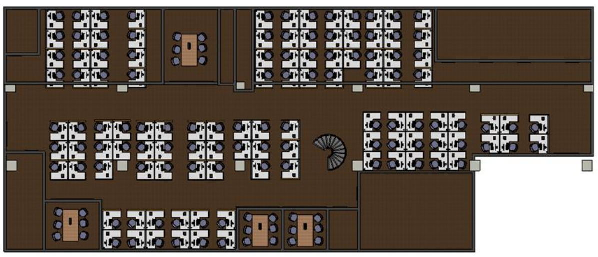

Figure 6: Floor plan of layout 2 (same as layout 1)

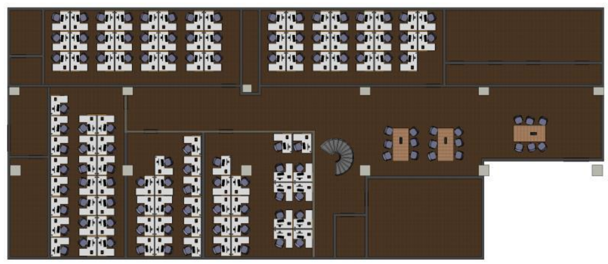

Figure 7: Floor plan of layout 3

Table 1: Characteristics of different layout design plans

Characteristics	Layout 1 (original plan)	Layout 2 (privacy-oriented plan)	Layout 3 (enclosed intradepartmental-shared plan)
The type of office based on enclosure (Danielsson and Bodin 2008)	Open-plan office with limited partitions	Cubicles with high partitions	Enclosed shared office
The height of partitions	1.1 m	1.5 m	• Partitions between departments: full-height; • Partitions between individuals: 1.1 m;
The degree of transparency of partition wall	Non-transparent	Non-transparent	• Partitions between departments: semi-transparent; • Partitions between individuals: non-transparent;
The number of office furniture	111 sets	111 sets	103 sets
The number of discussion room/area	4 private discussion rooms	4 private discussion rooms	An open discussion area with 3 discussion tables

3.3 VR realization and interactions development

These three design plans with their corresponding models are then used to develop the VR prototypes for users to have better immersive experiences and evaluations. In addition, three interactive tasks, namely "Find your seat", "Work with computers", and "Communicate with co-workers", are created to imitate the daily activities in RSC and further reflect the critical indicators for office assessments. The purpose, procedure and developing process of each task are described respectively as follows.

3.3.1 Task 1: Find your seat

Task 1 is designed to mock up the process of finding workers' own seats as it is one of the real-life activities frequently occurring in the office. This task can also give participants an opportunity to get familiar with the characteristics of different spatial design plans, such as the height of the partitions, the scale of the personal workspace, the allocation of functional areas, and the color tone of the overall layouts. In this task, participants are required to navigate in the VR environments to find the seat.

To develop task 1, three full-scale virtual office models of different design plans are first established. Then, a certain number of non-player characters are created for better imitating the real-life condition. In addition, an explicit blue arrow hanging in the air is placed to directly point to the specific seat, which aims to mitigate the strangeness when workers walk through the unfamiliar offices. Figure 8 shows the scenes of task 1 in different layout design plans.

(a) Layout 1 (b) Layout 2 (c) Layout 3

Figure 8: Task 1 "Find your seat" in different layout plans

3.3.2 Task 2: Work with computers

Task 2 aims to mock up the scene that student researchers concentrate on their works while daily distractions occur suddenly, which allows users to interactively experience different work environments and further evaluate their pros and cons. In this task, participants are required to sit in front of their computers and complete the Stroop test, which is identified as a proper activity to reflect the daily research work since they both require high attention from individuals (Maher and von Hippel 2005). During the Stroop test, participants can follow the instructions and name the color of the word line by line. Meanwhile, their audios are recorded for performance analysis.

To develop task 2, 2 sets of 20 words with relevant instructions are presented on the virtual computer screen separately via User Interface (UI). In particular, the name and the color of the words are consistent in the first set while they are different in the second set. Also, words among different layout plans are the same but are placed in different orders. To enhance the realism, visual and acoustic distractions are created to disturb participants when conducting the Stroop test. The contents of both visual and acoustic distractions are designed in accordance with the real condition of RSC. The visual distractions refer to several virtual non-player characters walk around the participant's workspace while the acoustic distraction is set as a sound of crowd-talking plays in sudden during the Stroop test. The contents of distractions among different layout plans are the same but with different starting times. Figure 9 shows the scenes of task 2 in different layout design plans.

(a) Layout 1 (b) Layout 2 (c) Layout 3

Figure 9: Task 2 "Work with computers" in different layout plans

3.3.1 Task 3: Communicate with co-workers

Task 3 is to imitate the scene that student researchers have a conversation with their co-workers, which allows participants to explore the discussion areas provided by the designed plans. Participants are suggested to complete a series of multiple-choice questions and further choose a suitable place to finish the conversation.

This series of questions with several corresponding pre-defined answers are presented via UI in the virtual environment. The contents of these questions are designed to lead participants to observe the layout they are experiencing. In addition, an alternative option is always provided for participants to change the conversation site from their initial workspace to the discussion room for ensuring the success of the conversation. Participants are also free to hold their conversation in their initial workspace as long as they are satisfied with the surrounding environment. Distractions from environments, including the visual and acoustic distractions, are created in accordance with the characteristics of the layout plan. Regarding layout 1 and 2, distractions only occur in the participant's own workspace as the discussion room are designed as a private sound-proofing area. For layout 3, distractions occur in both initial workspace and the open discussion area to reflect the expected condition. In this task, the visual distractions refer to several non-player characters notice the conversation and turn their faces to stare at the participant while the acoustic distraction is to play a sound of crowd-talking in sudden. The design of these distractions is based on the real condition of RSC. Figure 10 shows the scenes of task 3 in different design plans.

(a) The initial place in layout 1 (b) The initial place in layout 2 (c) The initial place in layout 3

(d) The private discussion room in layout 1 (e) The private discussion room in layout 2 (f) The open discussion area in layout 3

Figure 10: Task 3 “Communicate with co-workers” in different layout plans

4 COMPARATIVE EXPERIMENT THROUGH USER PARTICIPATION

After developing the VR prototypes with interactive tasks, a comparative experiment is additionally conducted as shown in figure 11. First of all, the post-occupancy evaluation is adopted as an evaluation method where a questionnaire survey based on the office indoor environment quality management is developed to measure the clients’ satisfactions in terms of privacy, communication, distraction, workspace enclosure characteristics, storage, and adjustability (NRC 2001, O’Neill 1994). Then, student researchers in RSC are invited and further divided into two groups to experience different office design plans with or without the assistance of VR technology. After the experiment, participants are asked to evaluate these three design plans using the afore-mentioned questionnaire survey and further have an open-ended interview to discuss their preference of design approaches. Finally, a statistical analysis is implemented to reflect the difference of performances between the proposed framework and the traditional approach.

A preliminary result of the questionnaire survey is obtained by calculating statistical measures to analyze the dispersion of clients’ satisfactions from each group in terms of the afore-mentioned aspects (table 2). Regarding the open-ended interview, feedback from participants is summarized in table 3 to show the main pros and cons of the proposed design framework.

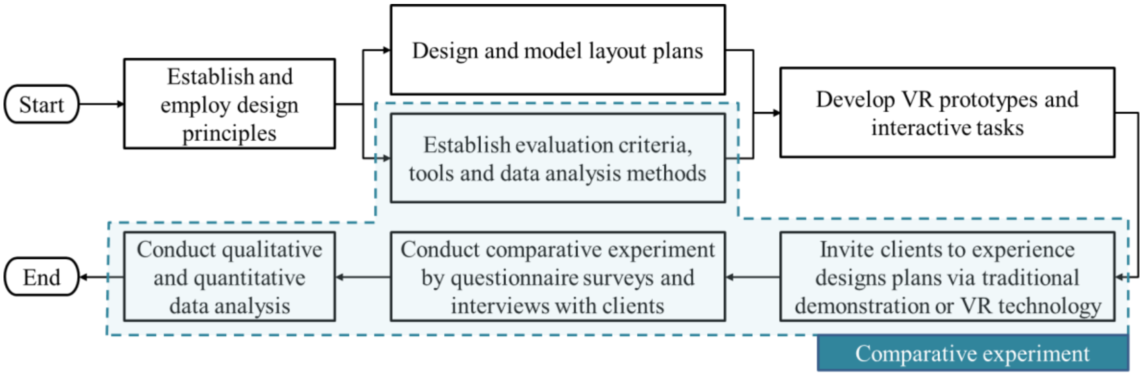

Figure 11: Flowchart of the development and validation of the proposed framework

Table 2: Statistical results of the questionnaire survey

Statistical measures	The mean of the standard deviation of samples	
Design approaches	Traditional approach	VR-based approach
Privacy	0.89	1.11
Communication	0.80	0.87
Distraction	0.87	1.09
Workspace enclosure characteristics	0.27	0.62
Storage	0.27	0.50
Adjustability	0.26	0.49
General satisfaction	0.89	0.81

Table 3: Feedback from student researchers on the proposed design framework

Advantages	Disadvantages
• Provide better visualization, e.g., it can visualize the geometric parameters vividly; • Present detailed information of the layouts to highlight their pros and cons; • Provide immersive experience; • Allow pre-set interactions to help users understand and experience different layouts; • Enhance users' participation; • Enable users to view from different perspectives freely.	• Make users feel dizzy and uncomfortable when experiencing for a long time; • Require a high level of realism otherwise it cannot provide immersive experience; • Require to display full-scale components otherwise it can cause misunderstanding.

5 DISCUSSION

The case study has elaborated that the proposed design framework is feasible to supplement the traditional design practice by providing immersive user experience and evaluation-oriented interactions. The immersive experience of navigating in full-scale design prototypes aims to enhance users' spatial cognition and demonstrate the characteristics of each layout design plan in detail. Besides, different from the spatial exploration and design function development proposed from previous research, the interactive tasks developed in this study are evaluation-oriented, which allow clients to experience their real-life activities in different virtual office models and further identify the advantages and disadvantages of each design plan concretely for layout assessment.

Several findings can be concluded from the preliminary result of the comparative experiment. The result of the open-ended interview indicates that better visualization, information cognition, immersive experience and interactivity are the main advantages of the proposed framework while motion sickness and the requirement for a high level of realism, especially for component size, are the potential issues need to be addressed and achieved accordingly. Regarding the result of the questionnaire survey, it shows that participants using the VR-based approach can get a higher dispersion value than those using the traditional approach in general (table 2). In other words, participants using the VR-based approach can have more diverse feelings about these three office layouts in both psychosocial perceptions and environmental design features aspects. This preliminary finding is consistent with the descriptive feedback from participants in table 3 and can further serve as statistical evidence to support the statements concluded from previous qualitative surveys and exploratory case studies. The holistic process and result of the comparative experiment will be presented in detail in the future.

6 CONCLUSION

This research has proposed a VR-based spatial design framework to improve office design practices in terms of immersive user experience and interactive evaluation. The feasibility of the proposed framework is then validated by a case study, in which three different layout design plans with three interactive tasks are established in accordance with the architectural design principles. In addition, a comparative experiment is conducted to examine the clients' satisfaction with different office design plans and summarize the pros and cons of the framework. The preliminary result shows that the framework enables users to be more sensitive to the difference between those design plans. Besides, the proposed framework is believed to provide better visualization, information recognition, immersive experience and interactivity for layout design and assessment. The result of this study also presents the potential of utilizing this framework to: 1) examine the design principles behind each design plan with the corresponding human behaviors; and 2) integrate clients' involvement into layout design and evaluation to have a better understanding between architects and clients. Future work will include a holistic analysis of the comparative experiment to validate the effectiveness of the framework.

7 ACKNOWLEDGMENT

The authors would like to thank 57 potential occupants from the Faculty of Engineering in HKU for their opinions on redesigning RSC. The authors also appreciate 7 architects from Tsinghua University, University College London and HKU for their layout design instructions.

8 REFERENCES

Adenauer, J., Israel, J.H. and Stark, R. 2013. "Virtual Reality Technologies for Creative Design." In*CIRP Design 2012*, 125–35. London: Springer London. doi:10.1007/978-1-4471-4507-3_13.

Berg, L.P. and Vance, J.M. 2017. "Industry Use of Virtual Reality in Product Design and Manufacturing: A Survey." *Virtual Reality* 21 (1). Springer London: 1–17. doi:10.1007/s10055-016-0293-9.

Budziszewski, P., Grabowski, A., Milanowicz, M., Jankowski, J. and Dzwiarek, M. 2011. “Designing a Workplace for Workers with Motion Disability with Computer Simulation and Virtual Reality Techniques.” *International Journal on Disability and Human Development* 10 (4): 355–58. doi:10.1515/IJDHD.2011.054.

Danielsson, C.B. and Bodin L. 2008. “Office Type in Relation to Health, Well-Being, and Job Satisfaction Among Employees.” *Environment and Behavior* 40 (5): 636–68. doi:10.1177/0013916507307459.

Davies, R.C. 2004. “Adapting Virtual Reality for the Participatory Design of Work Environments.” *Computer Supported Cooperative Work* 13: 1–33. doi:10.1023/B:COSU.0000014985.12045.9c.

HKU (The University of Hong Kong). 2016. “What Is Research Student Centre (RSC)?” About Us @ RSC, Faculty Of Engineering. Accessed December 30, 2018. https://www.engineering.hku.hk/enggrsc/about.html.

Kok, W., Meyer, M., Titus, S., Hollis-Turner, S. and Bruwer, J.P. 2015. “The Influence of Open Plan Work-Environments on the Productivity of Employees: The Case of Engineering Firms in Cape Town.” *Problems and Perspectives in Management* 13 (2): 51–56.

Lee, Y.S. 2010. “Office Layout Affecting Privacy, Interaction, and Acoustic Quality in LEED-Certified Buildings.” *Building and Environment* 45 (7): 1594–1600. doi:10.1016/j.buildenv.2010.01.007.

Maher, A. and von Hippel, C. 2005. “Individual Differences in Employee Reactions to Open-Plan Offices.” *Journal of Environmental Psychology* 25 (2): 219–29. doi:10.1016/j.jenvp.2005.05.002.

NRC (National Research Council). 2001. *Learning from Our Buildings: A State-of-the-Practice Summary of Post-Occupancy Evaluation*. Washington, DC: The National Academies Press. doi:10.17226/10288.

O’Neill, M.J. 1994. “Work Space Adjustability, Storage, And Enclosure As Predictors Of Employee Reactions And Performance.” *Environment and Behavior* 26 (4): 504–26. doi:10.1177/001391659402600403.

Pungotra, H. 2012. “Virtual Reality in Concept Design.” *International Journal on Manufacturing and Material Science* 2 (2): 35–39.

Shiratuddin, M.F. and Thabet, W. 2002. “Virtual Office Walkthrough Using a 3d Game Engine.” *International Journal of Design Computing* 4 (540): 1329–7147.

Sundstrom, E., Herbert, R.K. and Brown, D.W. 1982. “Privacy and Communication in an Open-Plan Office.” *Environment and Behavior* 14 (3): 379–92. doi:10.1177/0013916582143007.

Walsh, J. 2015. “Designing Work: Collaboration versus Concentration in Open Plan Workspaces?” 12 (1). doi:10.21427/D7H44R.