MEASURING HUMAN EMOTIONAL RESPONSE TO ARCHITECTURAL MATERIALS IN DAYLIGHTING CONDITIONS

by

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A THESIS

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Primary Thesis Advisor

This architectural research aims to survey human emotional responses to variations in daylight and material conditions. Over the past several years, daylight research has prioritized task-related comfort conditions and energy conservation, with a more recent push towards the photobiological benefits of eye-level light exposure. The field has a research gap in understanding, measuring, and predicting the human-centric experience of daylight and materials. This research aims to measure the effect of daylight conditions (façade/roof openings) and material composition (wood, brick, concrete, white-painted gypsum) on human emotional responses using subjective ratings in an online survey. The methodology places a 360-degree camera within a physical room model to capture material and daylighting variations. The panoramic images are transferred into an immersive eye-level web-based survey, asking participants to describe their emotional responses through numeric appraisal ratings. Initial results show that brighter daylighting variations with larger window openings have a strong positive impact on human emotional response. Materials also are influential but to a lesser degree, with people responding best to scenes with white painted gypsum board and wood. The anticipated benefits from this research are improved understandings of human perceptions of space, material, and light interactions within the built environment.

This project opens a new frontier for analyzing how people visually respond to materials and spaces from the human perspective. By further understanding emotional response, this research can help inform material choices and lighting designs to promote human well-being in architecture.

Acknowledgements

This project has been an incredible growing experience for me the past two years and would not have been possible without the guidance and support from many people. I would like to thank my Primary Thesis advisor, Dr. Siobhan Rockcastle for introducing me to building science research and inspiring my curiosity. Thank you for challenging me to rethink what is possible with this thesis, pushing the project to an IRB approval for potential publication, to a submission for the Undergraduate Research Symposium, and to Japan for the Hart Howerton Travel Fellowship.

Thank you to my mentors at the Baker Lighting Lab. I greatly appreciate the help of Alen Mahic for his expertise and insight regarding image capture setups and data processing. Thank you, Anupam Satumane, for helping me learn and structure the Qualtrics surveys.

I would like to extend my gratitude to Dr. Trond Jacobsen for being my Honors College Representative and supporting me during all 5 years at the University of Oregon. Thank you for encouraging me to pursue a thesis topic that I can apply to all my future architecture projects.

As I do not have a car, I was fortunate to have my friends Riley Chambers, Kevin Mueller, Sterling Miller, and Ran Liu drive me countless times to hardware stores around Eugene for material supplies. I would also like to thank my friend Pashmin Patil for her support, advice, and help on many stages throughout the project.

The survey reached over 200 people thanks to the help of the UO College of Design, UO Architecture & Environment, AIAS, and Clark Honors College in the distribution of my survey. I would also like to thank the CHC Mentored Research Program for two terms of funding to help cover material, equipment, and survey incentive costs.

Finally, I would like to thank my parents, Lori and Ed Wakil, for their continued support. Even though I come from a family in the sciences, I never thought I would be conducting research while pursuing a career in architecture. I would like to dedicate this project to my father and grandfather, Dr. Salih Wakil, as I have a newfound appreciation for their lifelong dedication to science and research.

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Introduction

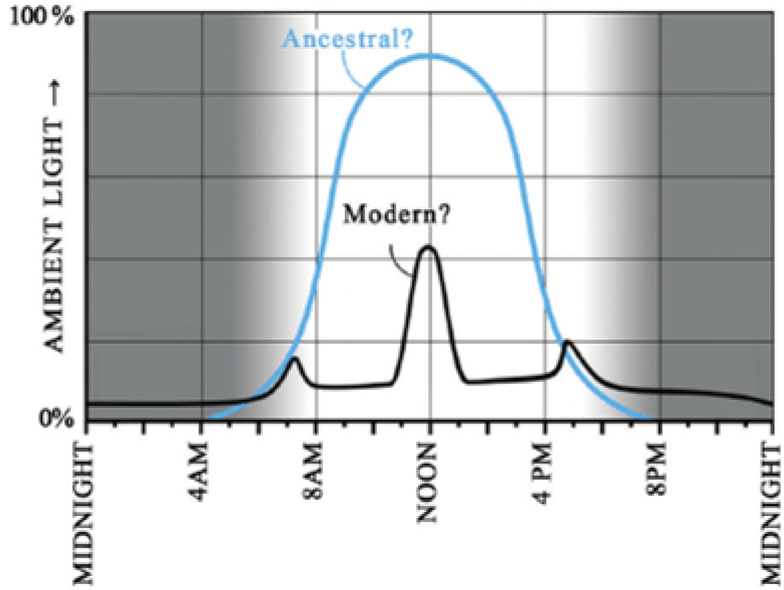

Figure 1.1: Daily exposure to ambient light (conceptual), ancestral versus modern lifestyles[1]

Americans, on average, spend 90 percent of their time indoors[2]. The lifestyles of modern humans today vastly contrast that of ancestral times, where humans reinforced their circadian rhythms spending most of their days outdoors and sleeping at night in compete darkness (fig 1.1). Such modern lifestyles means that it is essential for architectural designs to connect the people inside buildings with the outside throughout the day utilizing daylight. Daylighting is the cheapest lighting source, saves electricity, and is important for overall human wellbeing. In building sciences, most daylighting research has been dedicated to energy use and efficiency. More recently, daylighting research in buildings focuses on health benefits and task related comfort levels. In terms of metrics, most of these research projects quantitatively determine task

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[1] Heschong, Lisa. *Visual Delight in Architecture: Daylight, Vision, and View*. Illustrated by Garth von Ahnen, Routledge, Taylor & Francis Group, 2021.

2 U.S. Environmental Protection Agency. Report to Congress on Indoor Air Quality: Volume 2. EPA/400/1-89/001C. Washington, DC. 1989. Web.

performance illumination levels, and compliance targets for illumination, energy, and comfort. Yet, these focuses have created a research gap in understanding, measuring, and predicting the human-centric experience of daylight.

When compared to electric lighting sources, daylighting is of particular interest because of its full spectral power distribution of light (figure 1.2). The visible spectrum of daylight can most accurately reflect all colors with high intensity. On the contrary, electric lighting sources, such as fluorescent and incandescent lights, accurately reflect limited colors at high intensities. Light-emitting diode (LED) lights are a significant improvement to fluorescent and incandescent lights but still do not cover the full lighting spectrum as dynamically as daylight. Thus, daylight quality is essential when analyzing the impact of materials and their reflectance.

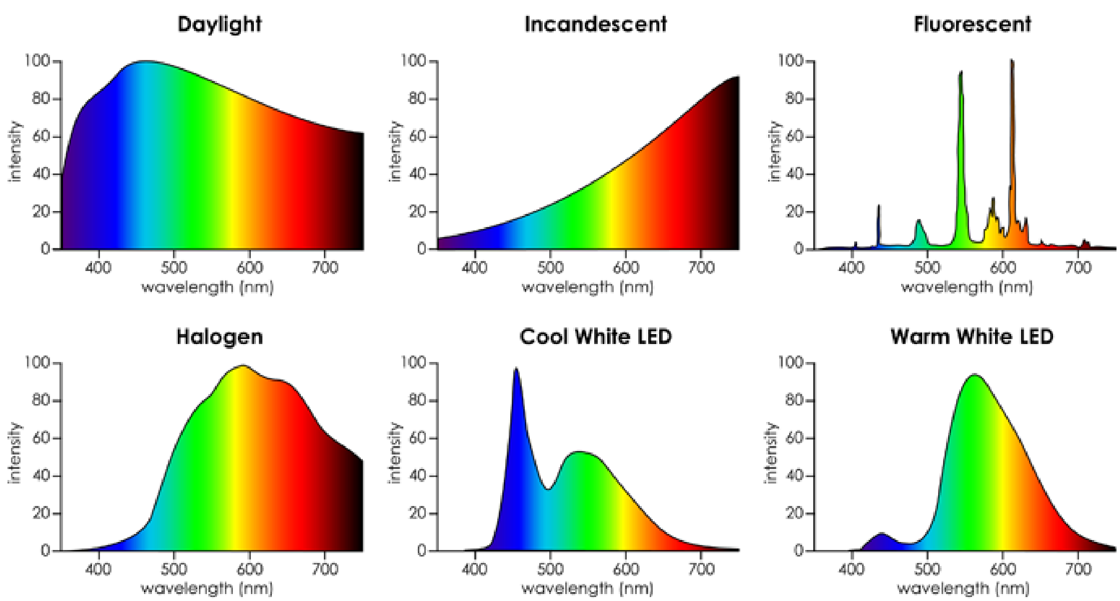

Figure 1.2: Spectral power distributions (SPDs) of natural daylight compared to artificial light sources[3]

[3] Klee, Paul. "2. Understanding the Light." *ELS - European Lighting School*, www.lightingschool.eu/portfolio/understanding-the-light/. Accessed 7 May 2024.

Daylight's dynamic cycles through time of day and year continuously influence the quality of light. Daylight's complexity is furthered by the building's location on earth and seasonal weather patterns that create different sky conditions, such as direct or overcast. These factors constantly influence the spectral qualities of daylight, determining its intensity and colors. This thesis captures lighting conditions on a singular day to have a consistent daylighting spectral profile with the variables being light aperture and material changes.

Light and materials are mutually dependent on each other. Surfaces reflect light and alter how light is perceived. Light's interaction with a material can vary based upon the properties of its surface, such as texture, reflectivity, and opacity. Specular materials, such as a mirror with a glossy finish, can reflect images of a light source visibly on the material surface. Matte material surfaces evenly diffuse light in all directions[4]. Additionally, these materials can vary in color. The color white is particularly noteworthy because it reflects all the visible wavelengths of light. A white wall reflects approximately 82% of incident light whereas a dark blue or green wall reflects approximately 7%[5]. Renowned architect Richard Meier famously designs entire buildings in the color white. He claims, "white is the light" and is a canvas to reflect all surrounding colors and light[6]. In this thesis, I utilized a matte white colored material as a control comparison with natural matte materials of color.

When planar material surfaces are assembled to form a volume, the form and scale of the volume significantly influence how the space is perceived. In this thesis, I created a physical model (10" x 10" x 8") scaled to 1:10 proportions of a medium sized room. The cubic volume

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[4] Millet, Marietta S., and Catherine Jean Barrett. *Light Revealing Architecture*. New York: Van Nostrand Reinhold, 1996. Print.
[5] Boylan, Bernard R. *The Lighting Primer*. 1st ed., Iowa State University Press, 1987.
[6] Jodidio, Philip, and Peter Gössel. *Richard Meier & Partners: White Is the Light*. Meier. Köln: Taschen, 2010. Print.

has interchangeable material surfaces and aperture openings. For instance, a white surface can be exchanged for a material surface. For lighting, a variety of apertures create different daylighting conditions within the volume, either by lighting from the top or the side. Thus, the lighting panels aperture openings vary in size, shape, and patterns. Moreover, the percentage of surface area open to light can dictate how bright the space is. These daylighting panels range from direct and exaggerated conditions with sharply contrasting light and shadow to indirect daylighting panels create conditions that diffuse light evenly through a space. Within these parameters, the physical daylighting model can create scenes with different materials and lighting conditions.

The type of daylight, the surface material qualities, and the ways daylight enters space all impact our perceptions of daylight within the volume. Our perception of daylighting, subjective in nature, greatly impacts how we experience the spaces we inhabit. Visual characteristics, such as brightness or contrast between light and dark, can create different atmospheres that provoke different emotional responses. Despite the subjectivity in perceptions, this thesis aims to find commonality in people's perceptions to daylighting and material conditions.

This project focuses on the human perspective, capturing panoramic images with a 360-degree camera placed at eye level within the physical model. The panoramic images are transferred into an immersive navigable web-based survey, asking participants to pan around the scenes and then describe their emotional responses through numeric appraisal ratings. For instance, participants are asked about their levels of calmness, pleasantness, or perception of brightness in scenes with specific daylighting and material conditions. This survey differs from conventional daylight metric systems that use a planar surface grid collecting light values with sensors. This human centric approach has few precedents and aims to understand the experiential qualities of daylighting. By measuring the impact daylighting variables have on human emotional response, this thesis can help inform material choices and lighting designs to promote human well-being in architecture.

This research aims to measure the effect of daylight conditions (façade/roof openings) and material composition (wood, brick, concrete, white-painted gypsum) on human emotional responses using subjective ratings in an online survey.

Literature Review

This architectural research aims to survey human emotional responses to variations in daylight and material conditions using a physical mock-up, 360-degree camera and online survey. Over the past several years, daylight research has prioritized task-related comfort conditions and energy conservation, with a more recent push towards the photobiological benefits of eye-level light exposure[7][8]. Research projects have typically studied task-plane illumination levels, and compliance targets for achieving comfort and energy-efficiency. The field has a research gap in understanding, measuring, and predicting the human-centric experience of daylight. This lighting research prioritizes the human perspective and experience, placing participants at eye level through web-based virtual reality surveys in different lighting and material conditions to survey their emotional response.

In architectural literature, there has been a broad consensus that daylighting profoundly impacts the emotional and sensual perceptions of space[9][10]. In Stephen Holl's *Questions of Perception*, Holl et al. (2006) address the sensory experience in architecture as a collection of essays that connect the human perception and phenomenological experience people in architecture. They grapple with understanding a range of dynamic daylighting experiences and uses, such as time of day (day vs night), space, color, and material response[11]. In her book *Light Revealing Architecture*, Marietta Millet (1996) directly acknowledges that "materials are

[7] Reinhart, Christoph and Mardaljevic, John. (2006) Dynamic daylight performance metrics for sustainable building design. Leukos, 2006; 3: 7–31.
[8] Lucas, R.J., Peirson, S., Berson, D.M., Brown, T.M., Cooper, H.M., Czeisler, C.A., Figueiro, M.G., Gamlin, P.D., Lockley, S.L., O-Hagan, J.B., Price, L.L.A., Provencio, I., Skene, D., Brainard, G.C. (2014) Measuring and Using Light in the Melanopsin Age. Trends in Neuroscience, vol. 37, no. 1, 2014, pp. 1-9,
[9] Safont-Tria, Jordi, Sanford Kwinter, and Steven Holl. Steven Holl: Color, Light, Time. Color, Light, Time. Zurich, Switzerland: Lars Müller, 2012. Print.
[10] Pallasmaa, Juhani. *The Eyes of the Skin: Architecture and the Senses*. Somerset: John Wiley & Sons, Incorporated, 2012. Print.
[11] Holl, Steven, Juhani Pallasmaa, and Alberto Pérez Gómez. *Questions of Perception: Phenomenology of Architecture*. Phenomenology of Architecture. [New]. ed. San Francisco, CA: William Stout Publishers, 2006. Print.

important emotionally in relation to light" as people connect with their cultural settings and individual recollection. Millet shares that the sparkle on glass, depths of dark polished woods, and shadows on white walls all hold emotional messages, but Millet falls short in further exploring this relationship between materials and emotions[12].

In her book *The Architecture of Light,* Mary Ann Steane addresses the need for a more imaginative use of daylighting in architecture alongside a more careful use of electric lighting, to which society has become overdependent on[13]. In a survey-based project on electric lighting, Matheny et al. (2018) compared interior finish material palettes illuminated by different color temperatures to understand generational preferences between Baby Boomers (grew up with warm incandescent lights) and Millennials (grew up with cool-colored compact fluorescent or LED lights)[14]. Although this study has participants responding to the emotional intention of an environment, this study electric lighting color temperature changes (not daylight) to material palettes (not isolated material conditions). Electric lighting tends to create static visual conditions, whereas daylighting produces a plethora of dynamic temporal qualities and a broad spectral profile. Incorporating daylighting through windows can also be beneficial for access to views to nature. In a comparison of window and windowless study conditions, the presence of daylight with a view has been shown to have higher positive emotions (e.g., happy, satisfied) than negative emotions (e.g., sad, drowsy)[15].

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[12] Millet, Marietta S., and Catherine Jean Barrett. Light Revealing Architecture. New York: Van Nostrand Reinhold, 1996. Print.
[13] Steane, Mary Ann. The Architecture of Light: Recent Approaches to Designing with Natural Light. London: Taylor and Francis, 2012. Print.
[14] Matheny, Rebekah, and Emily L. Bell. "Light's Impact on Color, Materials, and People's Preferences." International journal of architectonic, spatial, and environmental design 12.2 (2018): 41-49. Print.
[15] Ko, Won Hee, et al. "The Impact of a View from a Window on Thermal Comfort, Emotion, and Cognitive Performance." *Building and Environment*, vol. 175, 2020, pp. 106779-, https://doi.org/10.1016/j.buildenv.2020.106779.

A study by Flynn et al. (1979) lays the groundwork for methods and procedures that are still the gold standard for measuring subjective impressions in lighting environments through semantic differential rating scales for factor analysis, multidimensional scaling, and observation methods[16]. Franz et al. (2005) implemented the semantic differential scaling technique to quantify relations between emotional experience and architectural space in an early study that demonstrated effectiveness in utilizing Virtual Reality for basic architectural research[17]. In a separate study, utilizing a VR tool has been shown to enhance methods of for lighting design practice through representation of lighting at a 1:1 scale from the human perspective[18]. Sawyer et al. (2019) utilizes a Virtual Reality survey analyzing the impact of brightness perceptions in an office space for participants using a semantic differential scale with primary variables included shading design patterns, rendering materials, and furniture arrangements. The study's main finding was a clear association with participant's satisfaction with brightness and other perceptual impressions, such as perceived pleasantness, interest, and overall ambience[19]. Yet, this realistic office simulation does not isolate different material and lighting conditions.

Moscoso et al. (2021) conducted a virtual reality study asking participants to rate on a Likert-type scale different sky type lighting conditions of rooms with varying window sizes. The fenestration not only affects lighting levels, but also spatial perception. Perception questions asked participants to rank different emotions (e.g., pleasantness, calmness, excitement, amount

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[16] Flynn, John E., et al. "A Guide to Methodology Procedures for Measuring Subjective Impressions in Lighting." Journal of the Illuminating Engineering Society 8.2 (1979): 95-110. Print.
[17] Franz, Gerald, et al. "An Empirical Approach to the Experience of Architectural Space in Virtual Reality—Exploring Relations between Features and Affective Appraisals of Rectangular Indoor Spaces." *Automation in Construction*, vol. 14, no. 2, 2005, pp. 165–72, https://doi.org/10.1016/j.autcon.2004.07.009.
[18] Jelvard P, Mullins M. 2019. The use of VR technologies to enhance methods for lighting design practice. 7th eCAADe Regional International Symposium; 2019 May 2-3; Aalborg, Denmark. p. 97–102.
[19] Sawyer, Azadeh O. and Chamilothori, Kynthia, "Influence of subjective impressions of a space on brightness satisfaction: an experimental study in virtual reality." SIMAUD '19: Proceedings of the Symposium on Simulation for Architecture and Urban Design, 2019.

of view, brightness). The findings show that the type of space also affects window preferences[20]. This thesis similarly aims to further explore perceptual response in virtual reality to the relationship between window sizes and aperture variations. Yet, this thesis also aims to examine he role of material changes in perceptual response.

A study by Rockcastle et al. (2017) addresses shortcomings of current lighting metrics with respect to human perceptions, which analyze two-dimensional task surface illumination and prioritize glare-based discomfort. Their study utilizes an online survey where online subjective ratings of daylight composition in high dynamic range (HDR) renderings are analyzed to create a predictive algorithmic model for visual interest in daylit[21]. In 2021, Rockcastle et al. compared survey responses of dimmable lighting conditions of participants in the real world and virtual reality head-mounted-displays. It was found that participants found scenes in VR brighter than scenes in physical space[22]. Most recently, Rockcastle et al. compared 2D-perspective images, immersive panoramic images on a web survey, and VR Head-Mounted Displays. Results showed that VR Head-Mounted Displays and immersive navigable panoramic web-based scenes more closely aligned with ratings to physical spaces with less error than 2D perspectives[23]. In accordance with these findings, this research thesis utilizes immersive panoramic web-based images.

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[20] Moscoso, Claudia, et al. "Window Size Effects on Subjective Impressions of Daylit Spaces: Indoor Studies at High Latitudes Using Virtual Reality." *Leukos*, vol. 17, no. 3, 2021, pp. 242–64, https://doi.org/10.1080/15502724.2020.1726183.

[21] Rockcastle, S., M. L. Amundadottir, and M. Andersen. "Contrast Measures for Predicting Perceptual Effects of Daylight in Architectural Renderings." Lighting research & technology (London, England: 2001) 49.7 (2017): 882-903. Print.

[22] Rockcastle, S., et al. "Comparing Perceptions of a Dimmable Led Lighting System between a Real Space and a Virtual Reality Display." Lighting research & technology (London, England: 2001) 53.8 (2021): 701-25. Print.

[23] Rockcastle, Siobhan Francois, et al. "The Use of Virtual Screens in Perceptual Studies on Electric Light: A Comparison Between 2D, Panoramic, Cardboard, and Head-Mounted Displays." *Leukos*, 2023, pp. 1–16, https://doi.org/10.1080/15502724.2023.2279517.

A study by Villa et al. (2013) found that 40 observers per data group are required for online-based experiments. At a sample size of 40 participants, the variance in *p*-value is 0, which is enough to identify the stimulus effect[24]. In reference to this standard, this research will target a minimum sample size of 40 participants per data group.

Of the above-mentioned studies, none analyzed the impacts of daylight composition and material palette on human emotional response. This proposal builds on the methods of Flynn et al. (1979) and Rockcastle et al., (2021) to capture lighting conditions from a scaled physical model and show them to participants using a web-based survey to record emotional responses with semantic differential rating scales. This proposal applies novel immersive research approaches to highlight the human architectural experience with respect to lighting and materials.

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[24] Villa, C. & Labayrade, R. (2013). Validation of an online protocol for assessing the luminous environment. Lighting Research & Technology 2013; 45: pp. 401-420.

Methodology

The methodology for this research was broken down into two phases. The first phase includes the fabrication of the physical daylighting model and capturing the daylighting conditions using a 360-degree camera. The second phase outlines my survey and data collection.

In the first phase, I created a physical model (10" x 10" x 8") to simulate a room environment at a 1:10 scale. The wall and ceiling surfaces of the box are interchangeable to allow for different material and lighting conditions. The interchangeable materials being tested are wood, concrete, brick, and gypsum board painted white. Each material has panels that are inserted into the model (10" x 10" for floor/ceiling panels and 10" x 8" for wall panels). A stone floor panel remained constant throughout all material and lighting conditions (figure 3.1).

Each material was fabricated into panels that were scaled to the 1:10 scale (figure 3.2). For gypsum, standard gypsum wallboard was cut into panel dimensions and painted using interior matte white paint. For wood, 3/16" plywood was cut into panel dimensions before laser cut etchings engraved a wood plank siding pattern at 1:10 scale. The wood was then stained. For concrete, Rockite brand mixture was poured into panel molds and then sanded up to 220 grits. Mini red model bricks at 1:6 scale was purchased from Acacia Grove and were assembled using stucco as mortar. Stone tile was cut for floor panel dimensions. For windows, clear sheet glass was scored and snapped into window panel dimensions for top and side lighting conditions. A sheet of mylar film was used with the glass for indirect diffuse lighting conditions. The white painted lighting panels were created by laser cutting 3/16" plywood panels to create window openings with mullions. For side lighting conditions, material ceiling panels were attached to the model's plywood lid using Velcro.

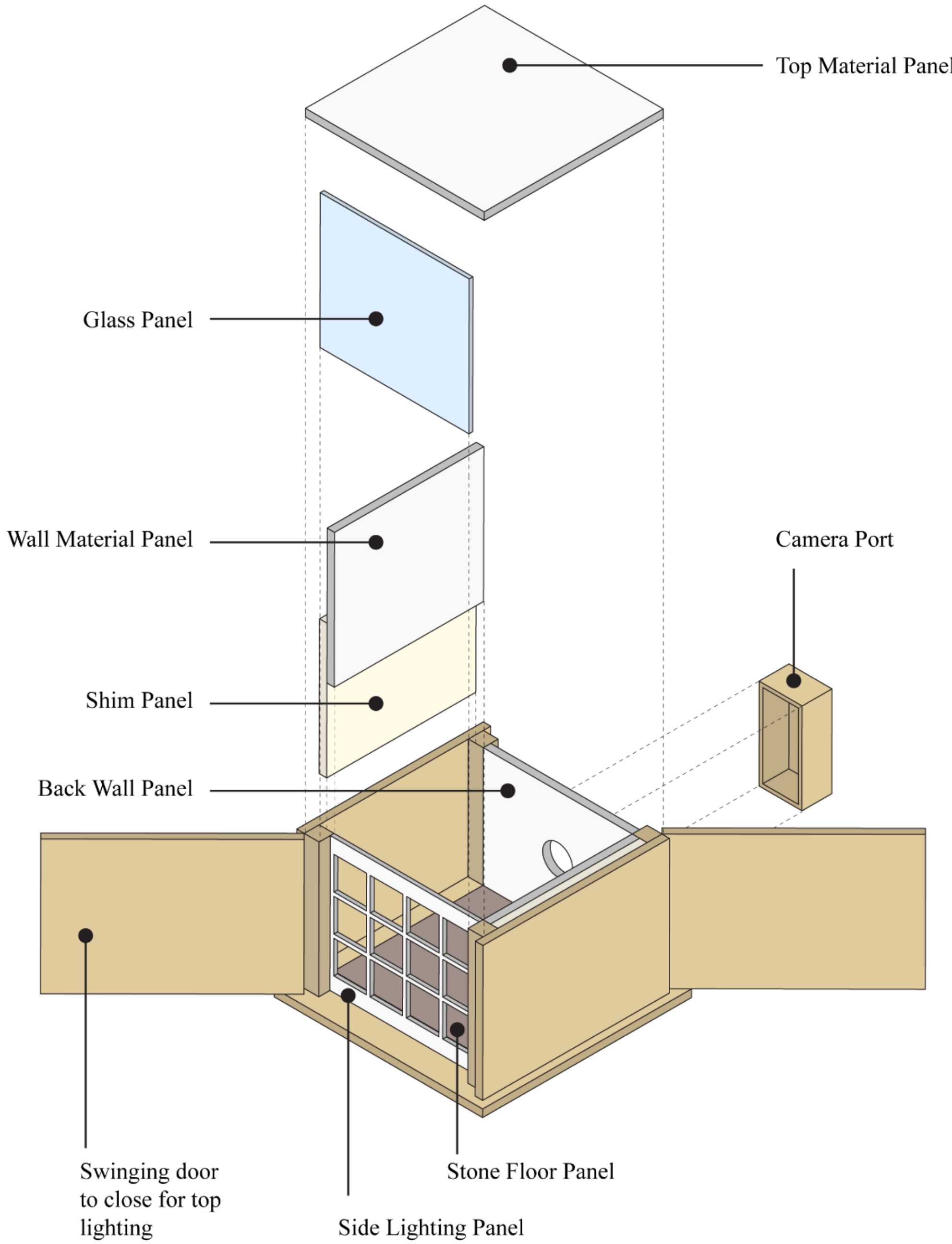


Figure 3.1: Exploded axonometric diagram of physical daylighting model assembly

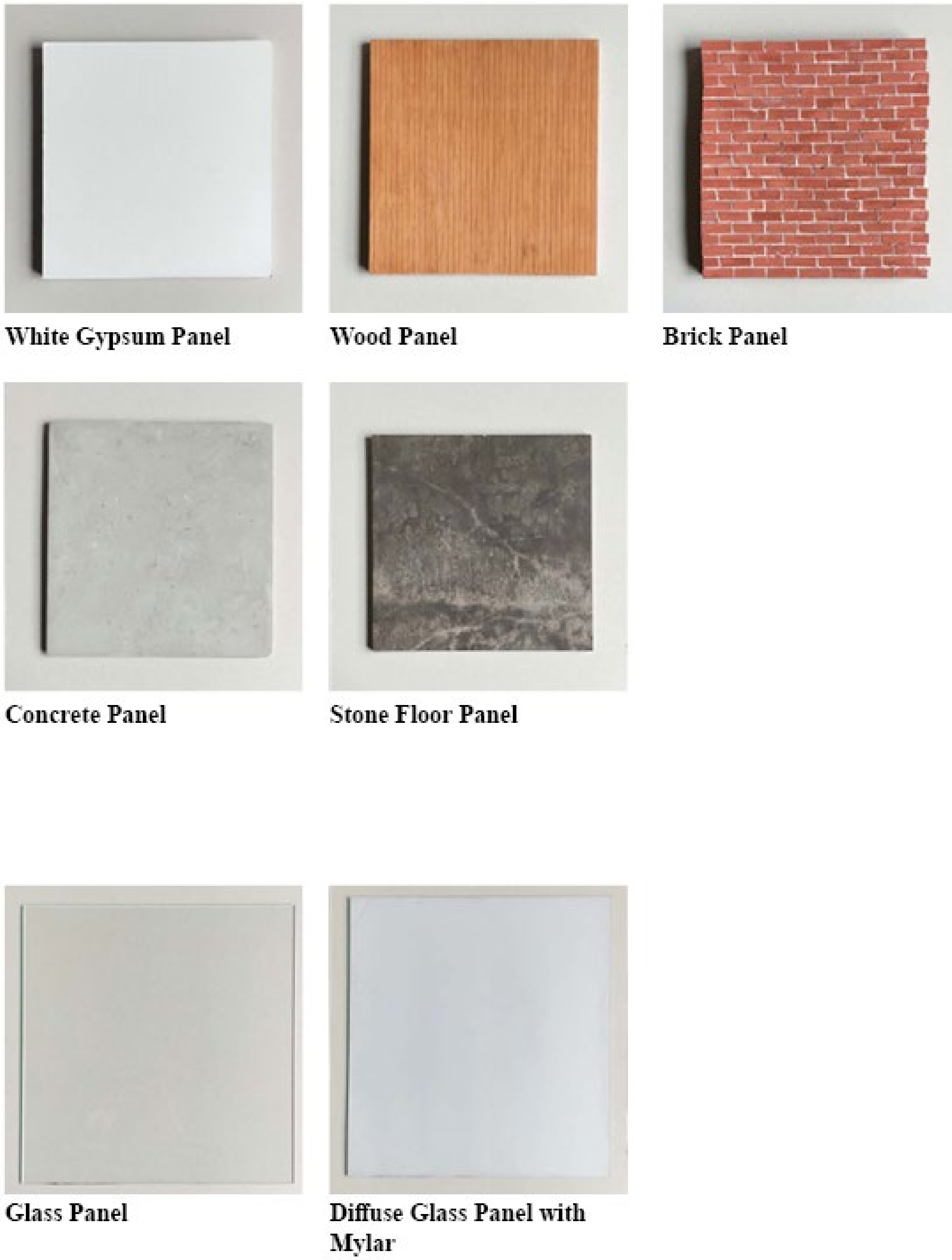


Figure 3.2: Material panels

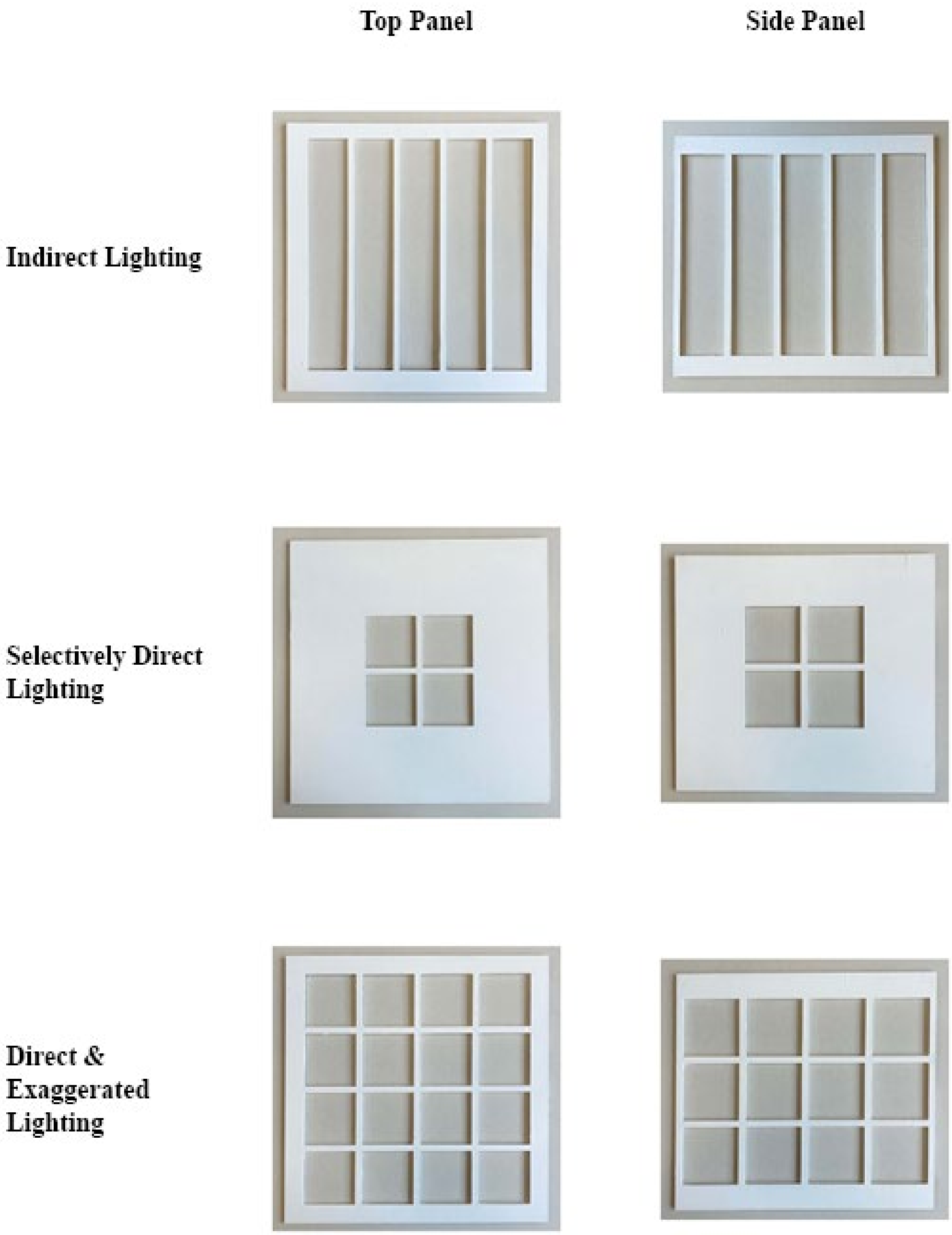


Figure 3.3: Lighting panels

Each material condition was tested outside with daylight entering either from the top or the side using lighting panel iterations (figure 3.3). The three daylighting conditions range from low contrast and variability to high contrast and variability. For both top lighting and side lighting conditions, lighting panels created either Indirect & Diffuse, Selectively Direct, or Direct & Exaggerated conditions for a total of 6 specific lighting conditions. Similar to the material panels, the lighting panels were inserted into the model (10” x 10” for ceiling panels and 10” x 8” for wall panels). For both top and side lighting conditions, the glass panes were layered outside of the lighting panel layer.

Once completed, the model was taken outside from 11am to 1pm on a clear and sunny February day in Eugene, Oregon to capture all lighting and material conditions (figure 3.4). The 360-degree camera used for this project was the Insta360 X3 360 camera for High Dynamic Range (HDR) images. For each scene, one of the camera’s two 180-degree fisheye lenses was inserted into a circular opening in the back wall centered 5 inches from the ground. This camera lens positioning scaled the box to simulate viewing a room from eye level. For both top and front lighting conditions, the camera lens was positioned facing south.

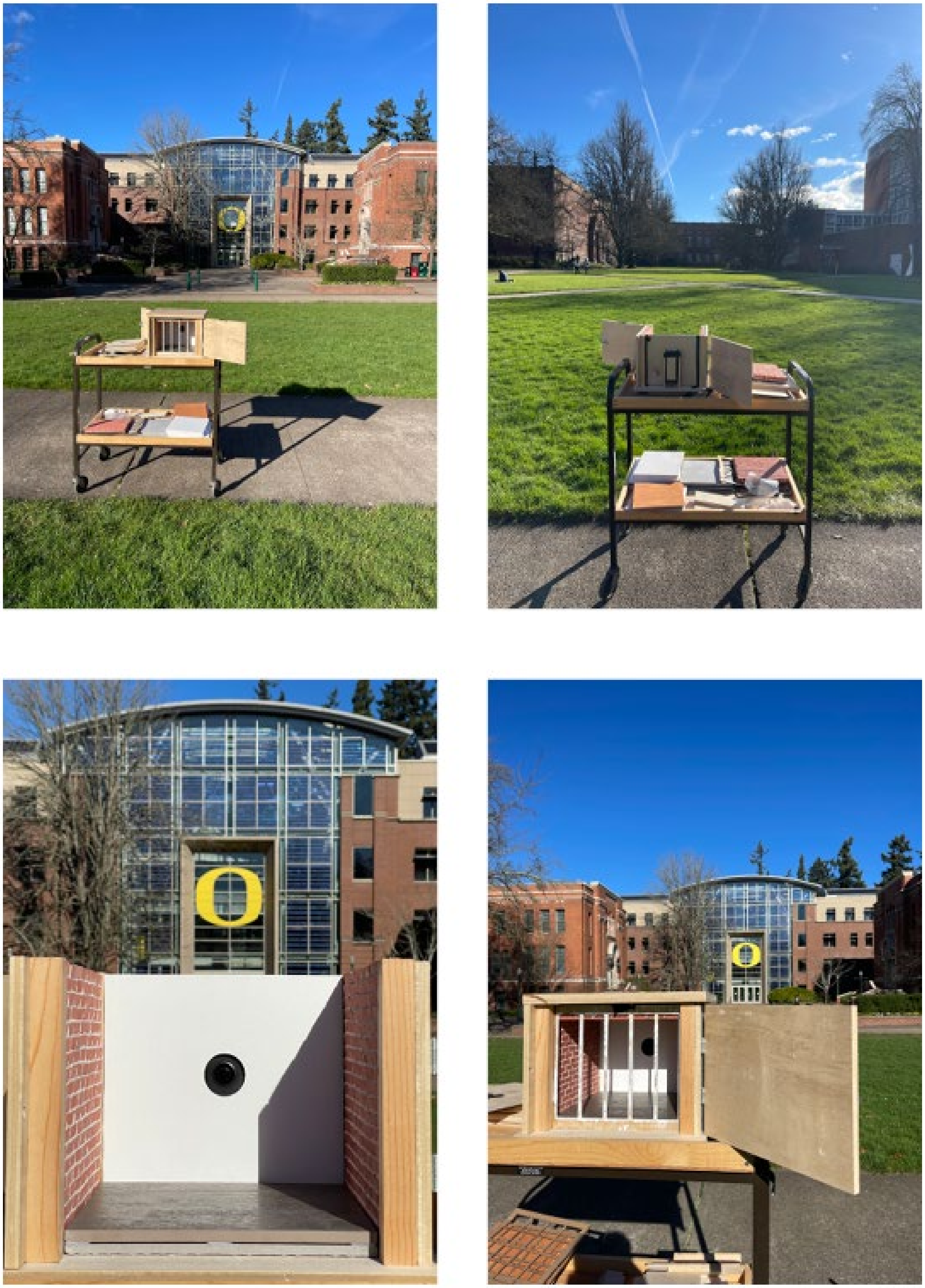


Figure 3.4: Physical daylighting model camera capture setup

Front view (top left), Rear view (top right), camera lens insert (bottom left), and side lighting setup (bottom right).

A singular 180-degree camera lens was chosen instead of using both 180-degree camera lenses to prevent the camera's automatic stitching lines between the two lenses from distorting the images. The second lens was covered while the scenes were captured in 360-degree HDR mode. After the images were captured, they were transformed into equirectangular JPG format. Next, the parts of the equirectangular image that were captured by the covered second lens were blacked out in photoshop. The images were then uploaded into Momento360 to be linked to the Qualtrics survey. The navigable 360-degree scenes were later embedded into the main Qualtrics survey using a html script.

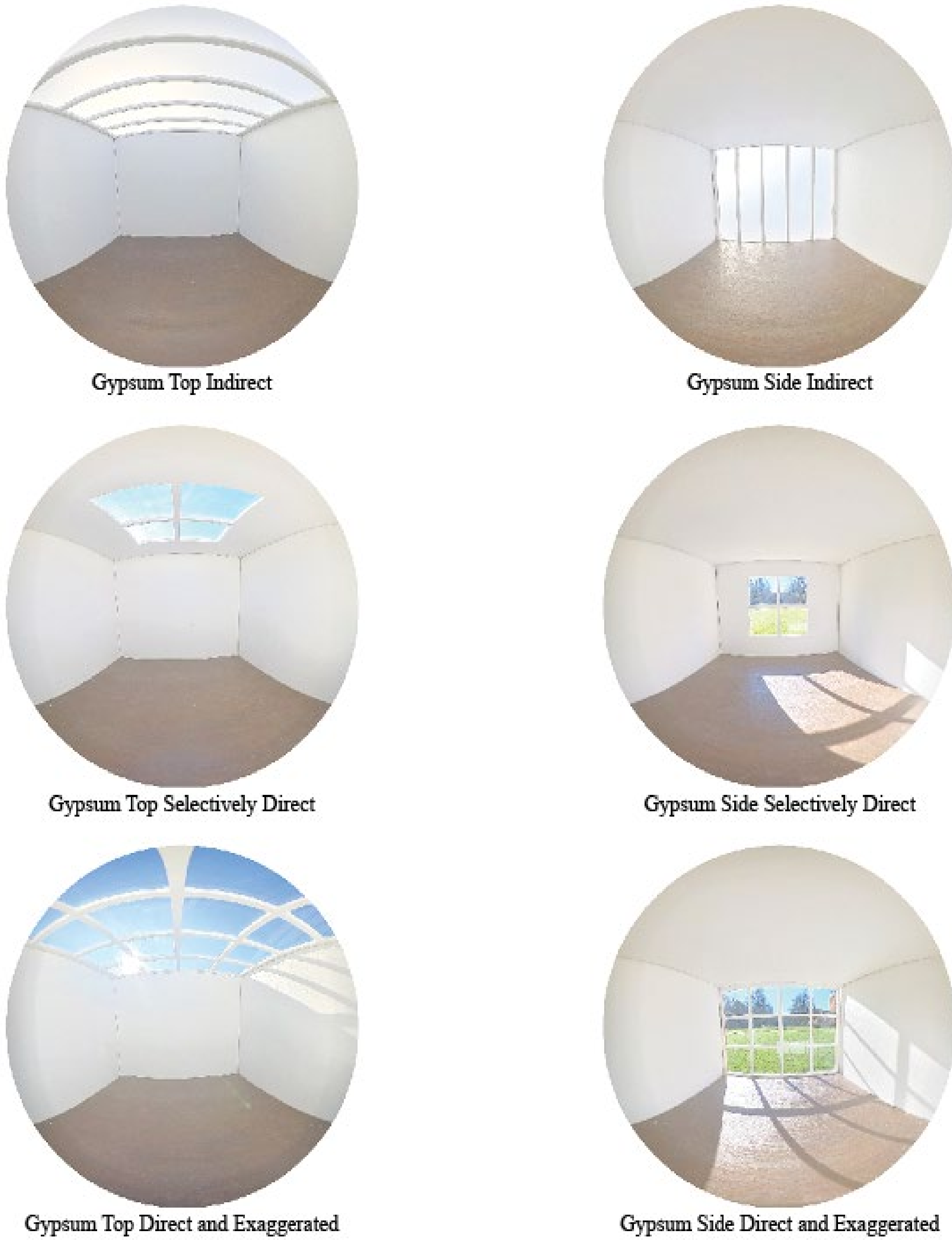


Figure 3.5: Gypsum group lighting conditions

Figure

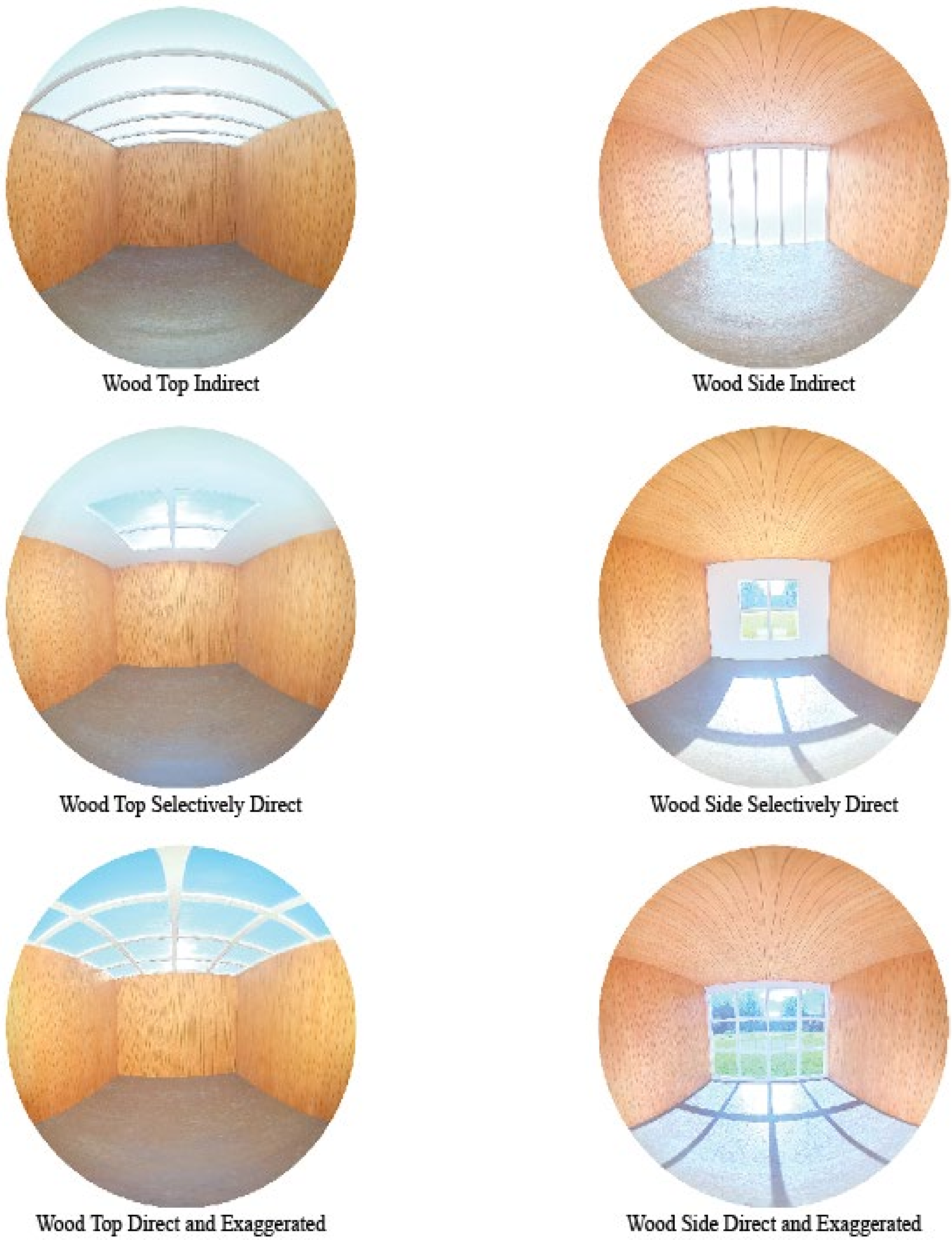


Figure 3.6: wood group lighting conditions

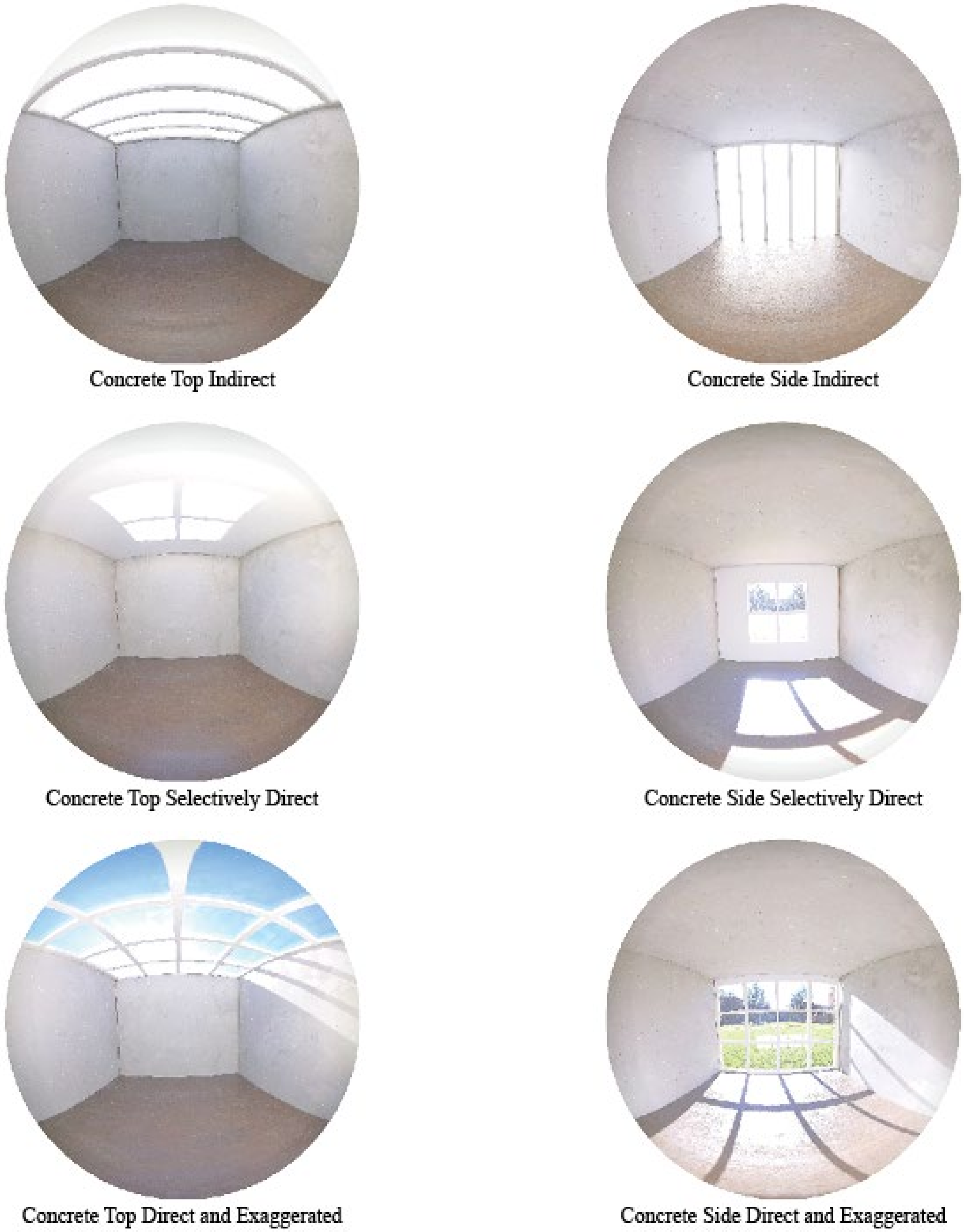


Figure 3.7: Concrete group lighting conditions

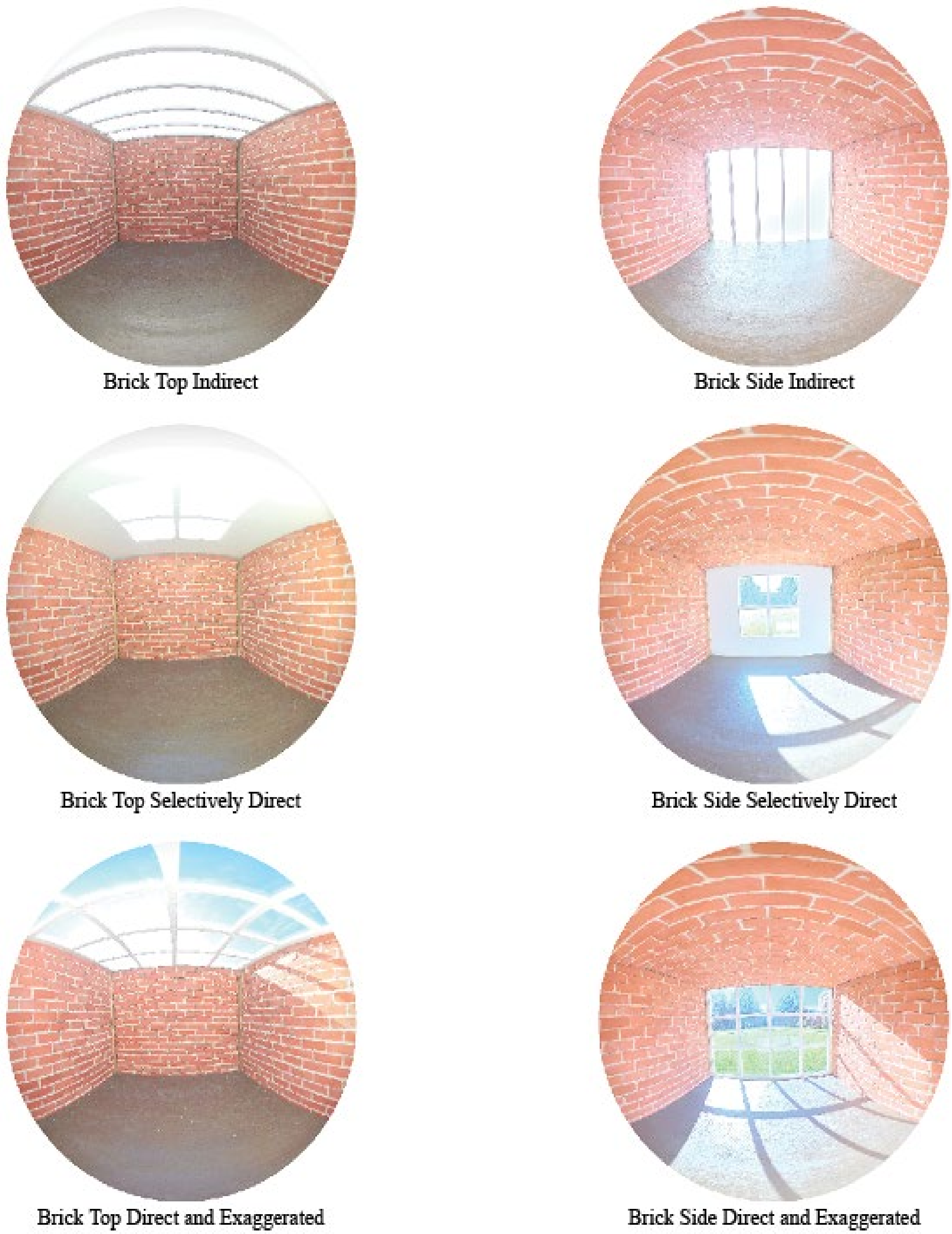


Figure 3.8: Brick group lighting conditions

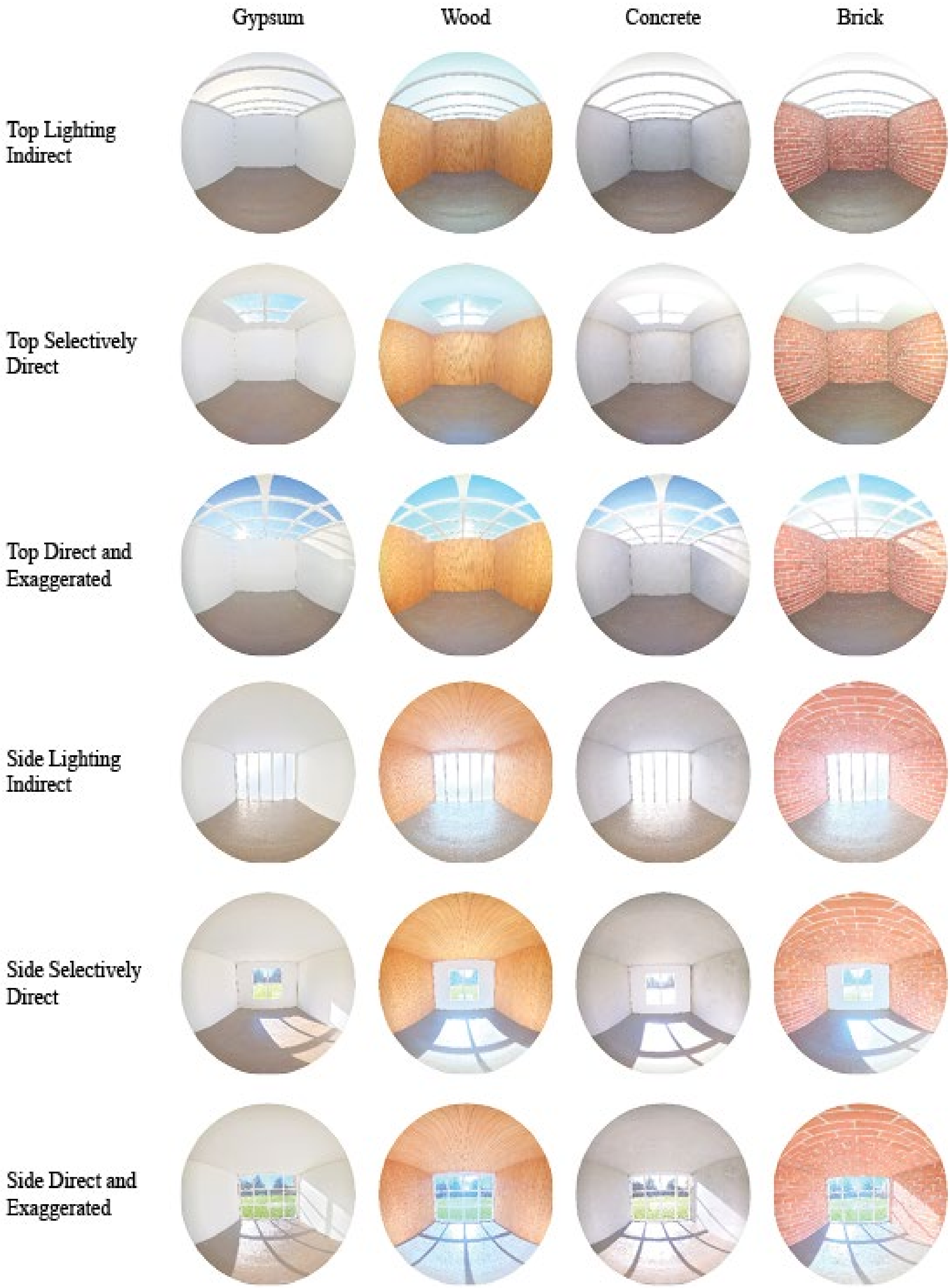


Figure 3.9: Comparison of all material and lighting conditions

In phase two of this research, a web-based survey was conducted. A web-based survey was chosen over a lab experiment using a head-mounted VR display to increase participant enrollment with lower experimental costs and collect data more quickly. Moreover, a web-based survey avoids risking delays in the research timeline from exposing our staff and participants to the possible transmission of the Coronavirus.

The survey experience was structured with 3 separate Qualtrics surveys (figure 3.11). First, the gateway survey was used to transition people from their mobile devices to receive the survey on their desktop, laptop, or tablet devices with larger screens (figure 3.10). The gateway survey presented participants with two options. First, participants already on their desktop, laptop, or tablet device clicked the option to continue to the survey and were then presented with a direct link. Second, participants on mobile devices would enter their email address to receive an automatic email with a direct link to the main survey to open from a device with a large screen. The gateway survey was necessary for people accessing the survey from QR codes using mobile devices.

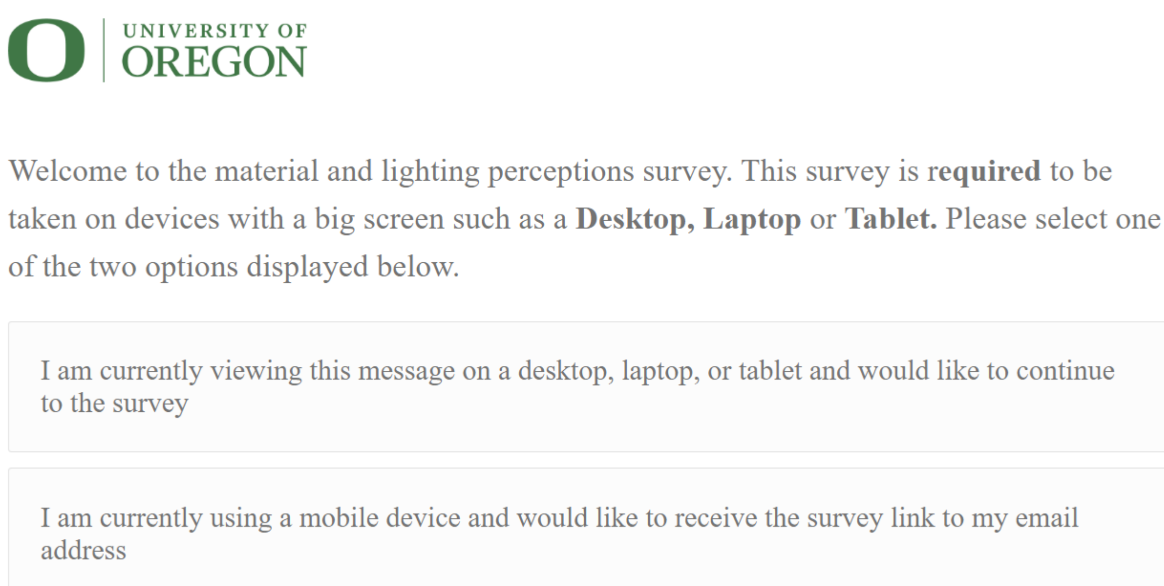


Figure 3.10: Gateway survey

The second Qualtrics survey was the main survey with all the survey questions (figure 3.13). Participants must agree to be using a desktop, laptop, or tablet. If not, the survey is ended, and they are unable to continue. Moreover, a Qualtrics device identifier was used to end the survey for participants on mobile devices claiming to be on a desktop, laptop, or tablet. All survey responses on the main survey were anonymous to prevent participants from being identifiable.

Participants that have an @uoregon email address were eligible to receive compensation for completing the survey. Thus, a third Qualtrics survey was used, decoupling the data from the main survey to preserve anonymity from previous responses. Upon completion, eligible participants clicked a link to the decoupled survey where they then entered their @uoregon.edu email address (figure 3.14). The decoupled survey link was only accessible to those who completed the main survey.

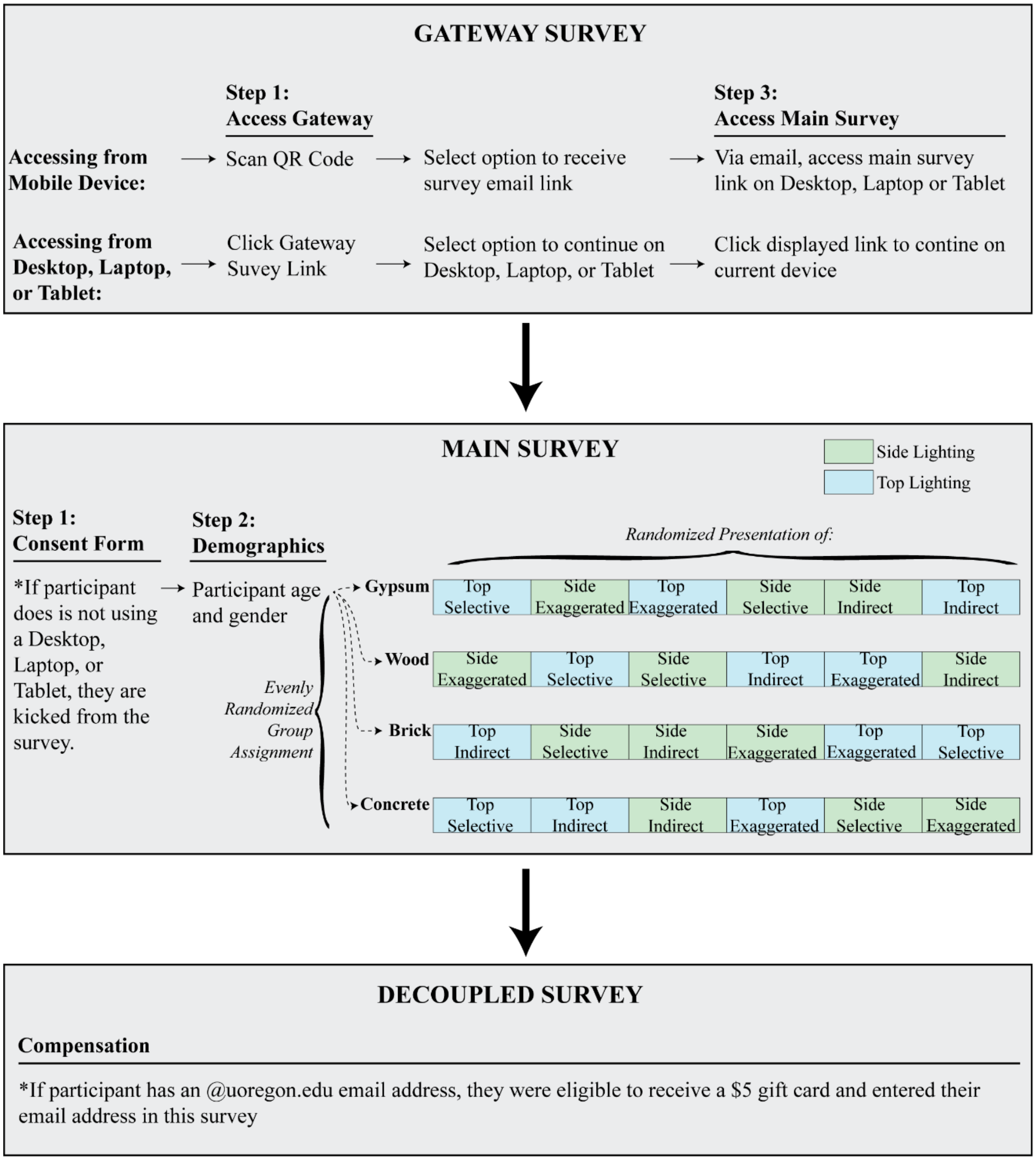


Figure 3.11: Qualtrics survey structure

The main survey experience was expected to take less than 10 minutes to complete (figure 3.12). Participants consented to that they are over 18 years of age, can read and understand English, and can adequately see the computer screen. The survey also required participants to take the survey at full brightness level on a device with a large screen: laptop, desktop, or tablet. The survey was comprised of experiencing 6 navigable 360-degee images and answering a series of subjective questions about each scene.

After the consent form, the survey began by asking demographic questions on age and gender. The age questions had three options: 18-34, 35-54, and 55 & older. The responses for the gender question "How do you describe yourself" had several options: Male, Female, Non-binary/third gender, Prefer to self-describe, and Prefer not to say. After completing the demographics questions, Qualtrics branch logic evenly randomized participants into 4 material groups: gypsum, wood, concrete, and brick. Each group had a fixed material condition while viewing all 6 lighting conditions in a random order (top lighting indirect, top lighting selectively direct, top lighting direct exaggerated, side lighting indirect, side lighting selectively direct, and side lighting direct exaggerated). For each of the six lighting conditions, participants panned around the panoramic web scenes before rating the scenes using a series of semantic differential ratings related to composition and emotional response. Participants were asked to rate the scenes based on the space feeling calm, exciting, interesting, pleasant, satisfying, coherent, contrasting, bright, and whether they feel comfortable spending time in the space. Lastly, participants were asked a yes/no question whether they described the lighting in the scene as glaring (figure 3.13). If they responded "yes," they were asked to rate the glare. The rating was based off Hopkinson's 9-level glare-rating scale but reduced to 5-levels (from imperceptible, perceptible, unacceptable, uncomfortable, to intolerable).

Please turn your screen brightness up to 100%.

Imagine yourself in the scene above and rate the following statements:

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
This space is calm	○	○	○	○	○
This space is exciting	○	○	○	○	○
This space is interesting	○	○	○	○	○
This space is pleasant	○	○	○	○	○
This space is satisfying	○	○	○	○	○
This space is coherent	○	○	○	○	○
This space is contrasting	○	○	○	○	○
This space is bright	○	○	○	○	○
I would feel comfortable spending time here	○	○	○	○	○

Figure 3.12: Main survey navigable scene and questionnaire

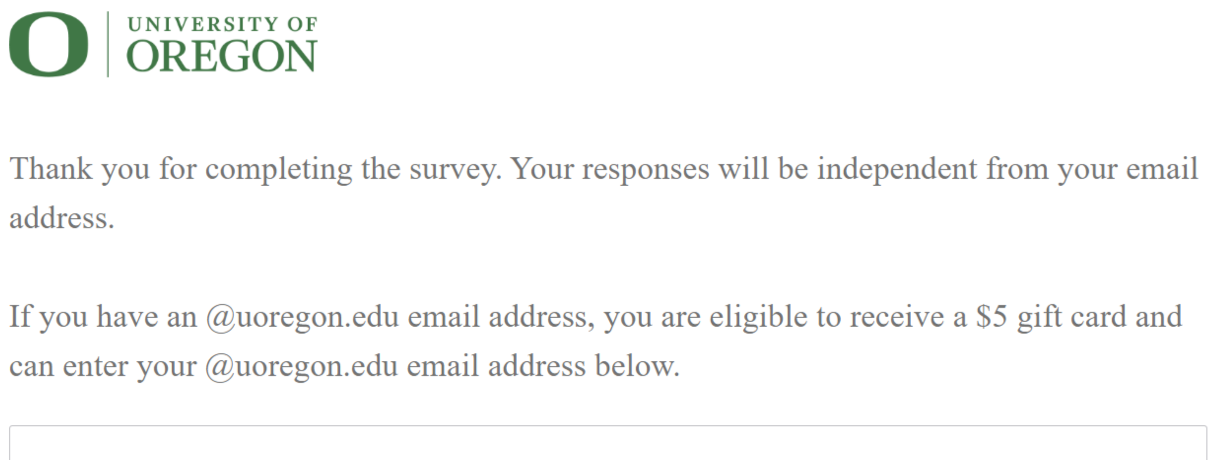

Would you describe the light in the scene as glaring?

Yes

No

	Imperceptible	Perceptible	Unacceptable	Uncomfortable	Intolerable
Would you rate the glare as:	◯	◯	◯	◯	◯

Figure 3.13: Main survey glare question and rating


UNIVERSITY OF OREGON

Thank you for completing the survey. Your responses will be independent from your email address.

If you have an @uoregon.edu email address, you are eligible to receive a $5 gift card and can enter your @uoregon.edu email address below.

Figure 3.14: Decoupled survey

The survey was distributed by posters, television prompters, in person class announcements, online class announcements, student email distributions, and social media stories (figure 3.15). Upon completing the survey, Participants with an @uoregon email address were eligible for a $5 Starbucks gift card compensation using funding from the University of Oregon Clark Honors College Mentored Research Program. This project was approved by the University of Oregon IRB, reference number: STUDY00000876.

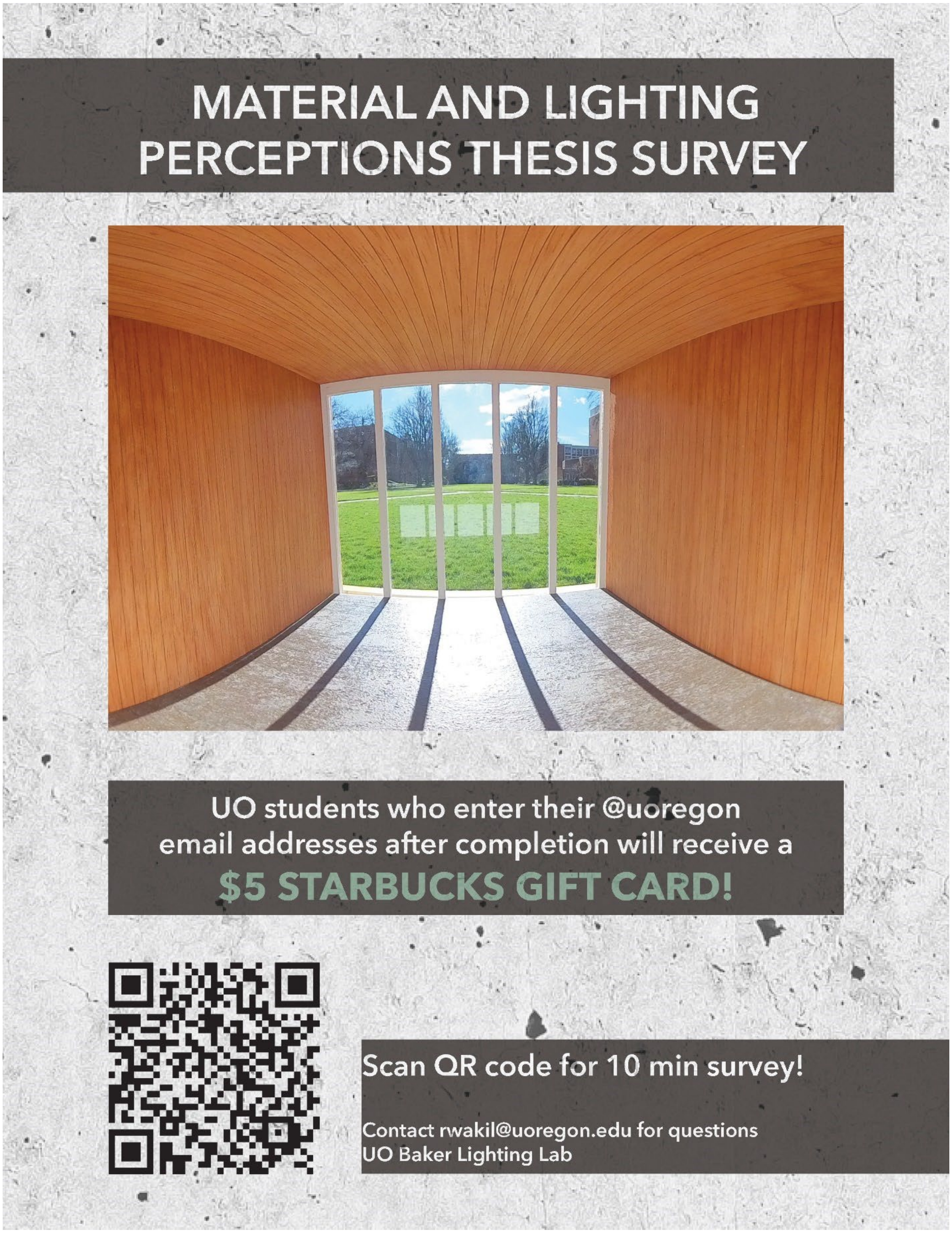


Figure 3.15: Survey poster announcement

Results

The survey received a total of 180 participants who took the survey. Over 90% of the participants were between the ages of 18 and 34 for a total of 168. There were 6 participants in both the 35 - 54 and 55 & older age ranges. For the gender demographics, 117 identified as female, 56 as male, and 3 as non-binary/third gender, 2 self-described and 2 preferred not to say.

The target population for this survey is a minimum of 40 participants per material group (as per Villa, 2013)[25] and the survey was shut down after that threshold was achieved. While open, the survey evenly randomized participants into the 4 material groups. The gypsum group received 45 participants, the wood group received 46 participants, the concrete group received 48 participants, and the brick group received 41 participants.

The data was sorted into two main comparison charts. The first chart focused on material groups irrespective of lighting conditions for each emotional response. This combined all lighting results for each question into one (figure 4.1). Gypsum received the highest mean values for calmness, pleasantness, coherence, and comfortability spending time in the space. Wood was also very highly ranked, particularly for interesting and contrasting. It is noteworthy that wood and gypsum were both considered to be the brightest material scenes as well. Concrete frequently had the 3rd highest means for most emotional responses. Brick was continuously considered the lowest ranked material across most scenes. One strong exception to these trends was the contrasting scene, where wood and brick had much higher mean values than gypsum and concrete.

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[25] Villa, C. & Labayrade, R. (2013). Validation of an online protocol for assessing the luminous environment. Lighting Research & Technology 2013; 45: pp. 401-420.

Contrarily, the second chart focused on lighting conditions irrespective of material groups for each emotional response. This combined all the material results into one (figure 4.2). There was significantly more variation in responses to lighting instead of material. For nearly each lighting condition (diffuse, selectively direct, and direct and exaggerated), the top lighting condition had a lower average mean than the side lighting condition. The most extreme example is the level of excitement across lighting conditions, with top selective direct lighting having a mean value of 2.18 yet side lighting direct selective having an overall mean value of 3.38. This was also consistent with interesting, where top light selective had a mean value of 2.46 and side light exaggerated had a mean value of 3.67. The scenes with the highest perceptual scores also have a correlation with the higher level of brightness, which ranged from top lighting indirect with the lowest brightness mean value of 3.51 and side lighting exaggerated with a very high mean value of 4.58. Side lighting that was direct and exaggerated was consistently one of the highest scoring lighting conditions across perceptual states. This condition also scored the highest for contrasting and had the most shadow play. Contrarily, Top lighting direct selective was consistently one of the lowest scoring lighting conditions. Noteworthy perceptual instances were responses to feeling calm. Top lighting exaggerated had the highest mean score of 3.41 as opposed to any indirect or selectively direct lighting conditions. This was noteworthy because top lighting exaggerated also had the second highest rating for excitement. It was anticipated that scenes with diffuse indirect lighting or selectively direct lighting would have been perceived as more calm than direct and exaggerated.

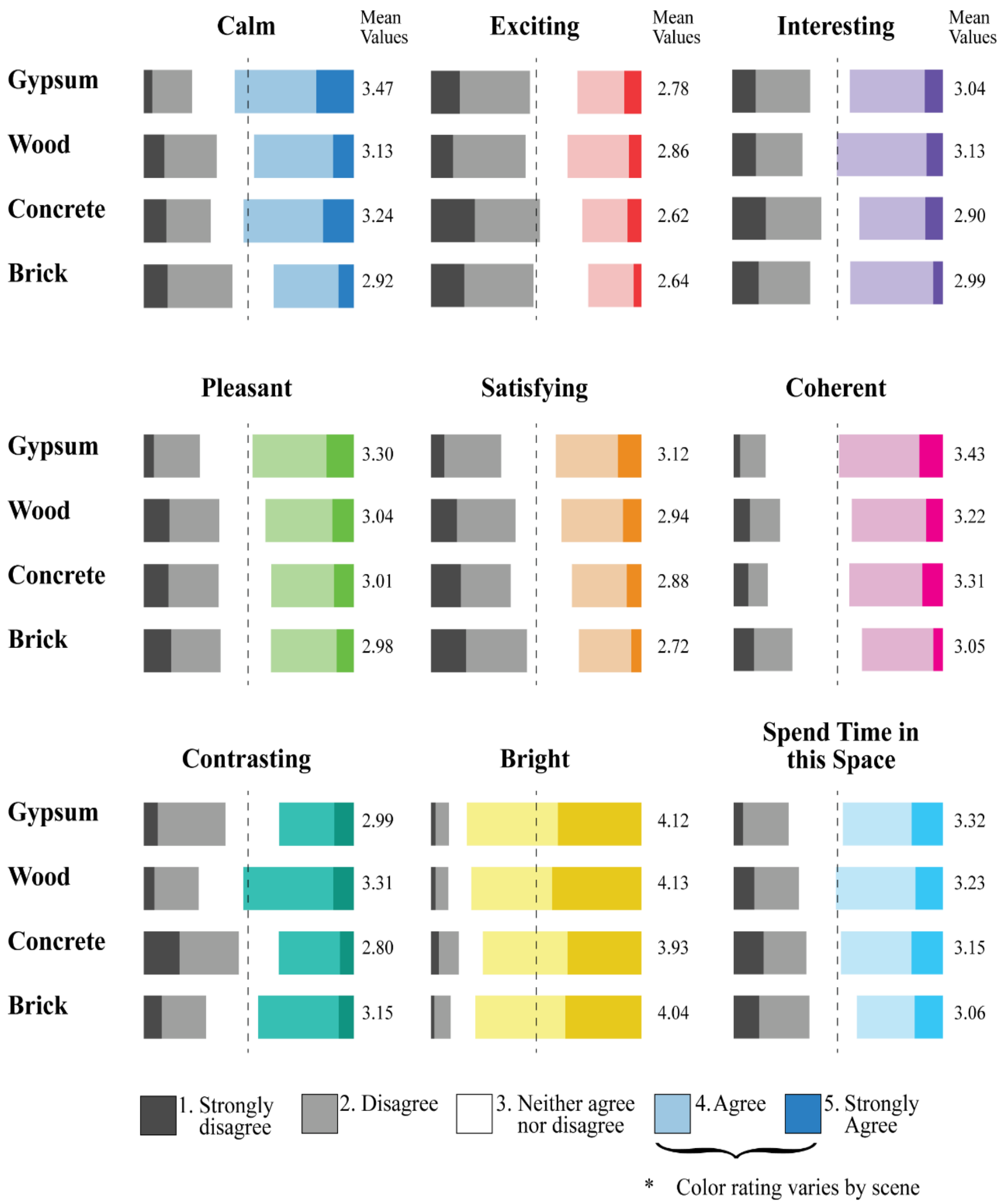

Figure 4.1: Material comparison charts

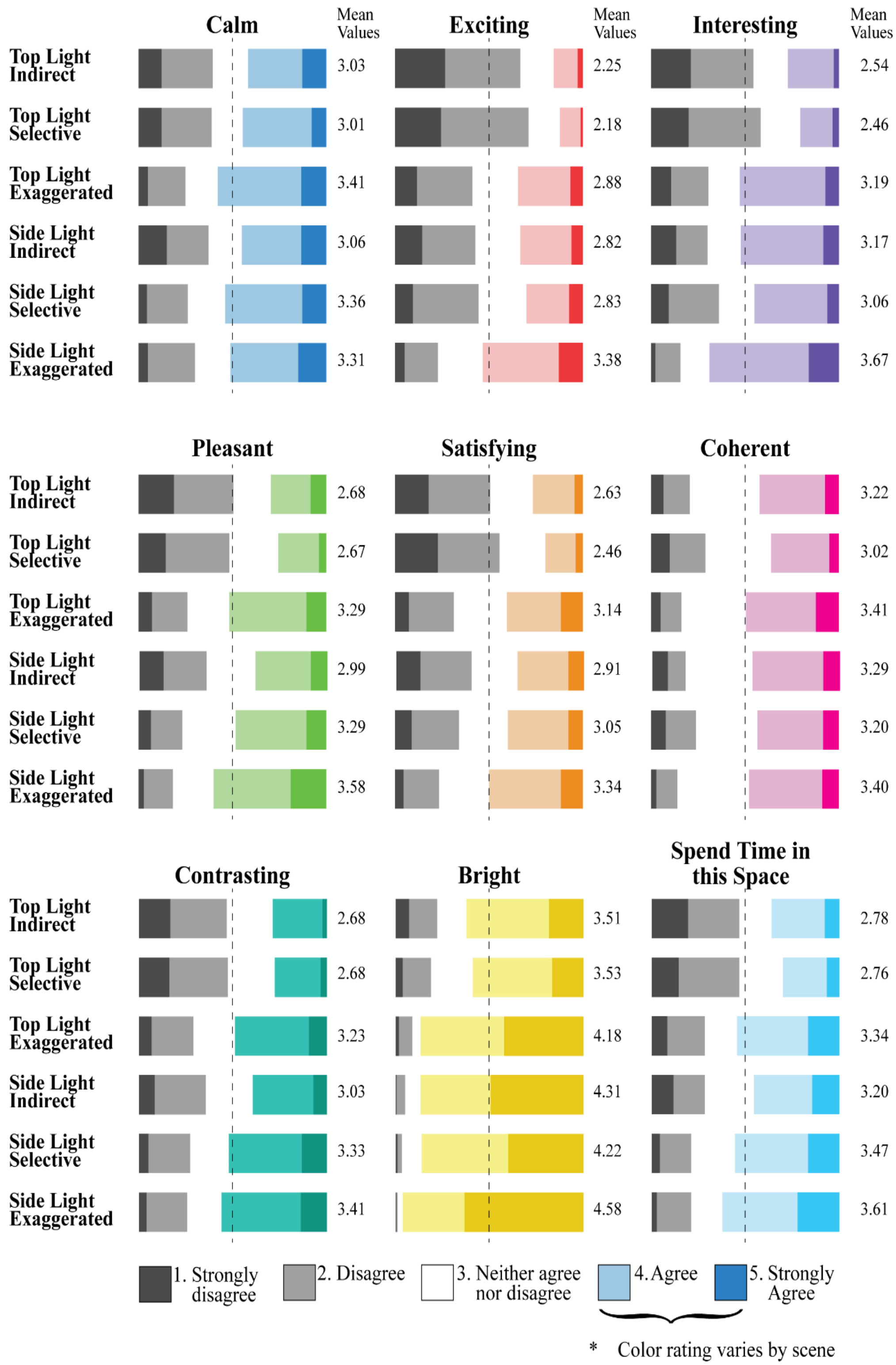

Figure 4.2: Lighting comparison charts

By comparing both general results for material and lighting responses, specific lighting and material scenes were analyzed by using a heatmap (figure 4.3). With gypsum and direct side lighting exaggerated receiving the highest mean values in their respective groups, the combination had one of the highest mean values of all conditions for comfortability spending time in the space at a value of 3.73. Moreover, the gypsum side lighting direct exaggerated ranked highest for excitement, pleasant, satisfying, and coherent. Concrete side lighting direct exaggerated scored the highest of all scenes for most willingness to spend time in the scene at a mean value of 3.75. This is surprising because concrete also scored the lowest of all materials in the top indirect scene for comfortability spending time in the space with a mean value of 2.29. For all scenes, the lowest mean score was also for concrete in the top indirect lighting scene with a mean value of 1.90 for excitement.

Regarding glare, scenes with wood frequently received the highest percentages of people saying glare was present. Wood scenes also had the highest mean value for brightness levels by a slight margin. Concrete recorded the lowest percentage of participants saying glare was present. Moreover, concrete had the lowest brightness scores of all the material groups.

Top Indirect

	Calm	Exciting	Interesting	Pleasant	Satisfying	Coherent	Contrastin	Bright	Spend time here?	Glaring? % Yes:
Gypsum	3.24	2.29	2.44	2.89	2.76	3.36	2.67	3.51	3.02	18%
Wood	3.28	2.65	2.93	3.02	2.80	3.20	2.85	3.63	3.02	22%
Concrete	2.58	1.90	2.35	2.13	2.33	3.25	2.42	3.42	2.29	10%
Brick	3.02	2.17	2.44	2.73	2.63	3.07	2.80	3.49	2.80	17%

Top Selectively Direct

	Calm	Exciting	Interesting	Pleasant	Satisfying	Coherent	Contrastin	Bright	Spend time here?	Glaring? % Yes:
Gypsum	3.40	2.29	2.47	2.98	2.80	3.18	2.80	3.73	3.02	11%
Wood	2.80	2.17	2.39	2.54	2.41	2.93	2.96	3.57	2.72	26%
Concrete	2.98	1.98	2.31	2.38	2.21	2.98	2.27	3.17	2.52	8%
Brick	2.85	2.29	2.68	2.80	2.41	3.00	2.71	3.68	2.78	12%

Top Exaggerated

	Calm	Exciting	Interesting	Pleasant	Satisfying	Coherent	Contrastin	Bright	Spend time here?	Glaring? % Yes:
Gypsum	3.33	2.91	3.24	3.24	3.13	3.51	3.13	4.49	3.09	67%
Wood	3.52	3.00	3.30	3.26	3.17	3.48	3.33	4.13	3.48	43%
Concrete	3.58	2.85	3.13	3.42	3.25	3.42	3.17	4.10	3.50	21%
Brick	3.17	2.76	3.07	3.22	2.98	3.20	3.29	4.00	3.29	12%

Side Indirect

	Calm	Exciting	Interesting	Pleasant	Satisfying	Coherent	Contrastin	Bright	Spend time here?	Glaring? % Yes:
Gypsum	3.78	2.87	3.22	3.42	3.24	3.60	2.76	4.16	3.56	38%
Wood	2.89	2.93	3.22	2.98	2.96	3.24	3.39	4.41	3.24	65%
Concrete	3.25	2.83	3.21	3.00	2.96	3.44	2.67	4.19	3.21	50%
Brick	2.24	2.63	3.02	2.51	2.44	2.85	3.34	4.49	2.76	73%

Side Selectively Direct

	Calm	Exciting	Interesting	Pleasant	Satisfying	Coherent	Contrastin	Bright	Spend time here?	Glaring? % Yes:
Gypsum	3.58	2.73	3.07	3.47	3.22	3.31	3.22	4.18	3.49	42%
Wood	3.24	3.00	3.11	3.15	3.13	3.17	3.61	4.39	3.52	67%
Concrete	3.52	2.83	2.88	3.40	3.02	3.27	3.10	4.08	3.60	38%
Brick	3.07	2.76	3.20	3.12	2.80	3.02	3.41	4.22	3.22	68%

Side Exaggerated

	Calm	Exciting	Interesting	Pleasant	Satisfying	Coherent	Contrastin	Bright	Spend time here?	Glaring? % Yes:
Gypsum	3.51	3.58	3.82	3.78	3.58	3.60	3.38	4.64	3.73	62%
Wood	3.02	3.37	3.85	3.28	3.17	3.28	3.74	4.63	3.41	83%
Concrete	3.54	3.33	3.50	3.75	3.50	3.52	3.19	4.65	3.75	54%
Brick	3.15	3.24	3.51	3.49	3.07	3.17	3.32	4.37	3.51	66%

Figure 4.3: Heatmap results for all material and lighting scenes

Discussion

This thesis found that there were general differences with material changes but significant differences variations in lighting conditions regarding human emotional response.

For materials, white painted gypsum was consistently one of the highest ranked materials, with wood often near the top as well. Scenes where either of these materials were present also had the highest perceived brightness levels with nearly identical mean values at 4.12 for gypsum and 4.13 for wood. Concrete had the most variability, ranking highest in the side lighting exaggerated condition but poorest in top indirect lighting condition. Brick was consistently one of the lower rated materials.

Daylighting conditions were mostly impacted by the surface upon which light entered the space and the amount of light that entered, influencing brightness levels, most clearly shown in scenes with a direct exaggerated lighting condition entering from the side. Overall, lighting conditions with the direct and exaggerated lighting panels scored highest for top and side panels respectively. It is noteworthy that the direct and exaggerated lighting panels had the largest percentage of window openings for direct light per panel, resulting in the brightest scenes. Indirect lighting panels scored better on top lighting conditions than side lighting conditions. Conversely, selectively direct lighting panels scored better on side lighting conditions than top lighting conditions. This would likely be influenced by the side direct lighting condition having a view to nature. The results for the transparent side lighting conditions could potentially have differed had there been no view to nature or view at all. The differences between the top and side lighting conditions could also be attributed to the notion of feeling trapped in a space (top lighting conditions with no wall windows) versus having a view to spaces beyond the room (side lighting conditions with transparent window).

There were several limitations to the thesis. For the physical model, the 4 materials are a general representation for entire material groups. For example, the wood and pattern chosen does not reflect all types of wood and patterns. This is also applicable to brick and concrete. The white gypsum wallboard was a consistent control material. During the camera captures, the camera was pointed south for all scenes. This limited the number of shadows visible in top lighting conditions compared to side lighting conditions. If the camera and physical model were rotated to face north, shadows would have been cast on wall opposite the camera, creating more variation and shadows between the lighting conditions. Even though a north facing camera was considered for top lighting conditions, we decided to maintain a south facing camera for all scenes to limit the number of variables.

For the survey, the primary population group was 18-34 participants who majority identified as female. Moreover, many of the participants were students in the UO College of Design familiar with architectural materials and daylighting. Results may have differed if there were a more diverse population group.

For the measurement of glare, participants who responded "yes" to describing the scene as glaring proceed to rank the glare on a 5-level scale (from imperceptible, perceptible, unacceptable, uncomfortable, to intolerable). Since different percentages of participants responded to this question for each scene, the 5-level scale was ultimately not used in the analysis. The analysis only referred to the percentage of participants who responded "yes" to glare. If the survey had been restructured, this scale could have been used if it replaced the other glare question and was an independent ranking question for all participants.

With this methodological framework, future studies follow this methodology to compare human emotional response to other materials. Additionally, this methodology could be applied to studies focusing on variations within specific material groups, from types of wood, brick patterns, and colors of concrete. For lighting, studies can compare lighting conditions at different times of year, or color explorations. Given that white painted gypsum was considered one of the highest scoring materials, future lighting studies can isolate this material across many more lighting conditions. The physical model box can be used for different purposes, such as replacing the 360-degree camera with a spectroscopy camera to record the impact of material changes on the spectral profile of daylighting. Overall, the flexible methodological framework of this thesis can help expand a new frontier for daylighting and material research.

Conclusion

This study found that primarily daylighting conditions, but also material palettes can be influential in human emotional response. Daylighting variations with higher brightness ratings generally correlated to stronger perceptual responses. These lighting conditions had larger window apertures for lighting. The highest ranked daylighting condition was the direct and exaggerated side lighting. The results for material choices had less variation than with lighting conditions. White gypsum board was frequently the most preferred material, ranking highest for calmness, pleasantness, satisfaction, and coherence. Wood was frequently one of the highest ranked materials as well. Concrete and Brick had a lot more variability and were lower ranked for emotional responses.

By placing the human experience at the forefront, I hope the novelty of my thesis will help expand our understanding of daylight analysis. The anticipated benefits from this research are improved understandings of human perceptions of space, material, and light interactions within the built environment. This project opens a new frontier for analyzing how people visually respond to materials and spaces from the human perspective. By further understanding emotional response, this research can help inform material choices and lighting designs to promote human well-being in architecture.

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