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Influence of Simulated Natural Light on Mood and Well-being Case study at Obos Living Lab, Oslo, Norway

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Abstract

Northern regions deal with low solar intensity and low solar angles, accentuating health and well-being issues such as sleeping problems or even seasonal affective disorder (SAD). Consequently, it showcases the urge for an artificial lighting system that can back up sunlight deficiency and address health concerns. Also, verisimilar sunlight simulation data is still scarce but has shown positive implications for individuals, as in accordance with other references. This article comprises the first part of an experiment at Obos Living Lab in Oslo, Norway. It uses a prototype that proposes to simulate natural light and evaluate potential impacts on subjects. By monitoring a group of participants, a series of questionnaires were carried out, taking into account the user's perception of the experimental space. The main focus was on the light and atmosphere generated by the prototype. Through parameters such as energy levels and motivation, it was possible to find correlations within a time frame to identify if there were general and individual improvements in well-being. Results reinforce the importance of simulated sunlight as it achieves positive psychophysiological effects on individuals. Therefore, the prototype could simulate sunlight with a natural quality of light.

Keyword: led sunlight simulation; circadian light; well-being; human perception

Citation

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Influencia de la luz natural simulada en el estado de ánimo y el bienestar. Estudio de caso en Obos Living Lab, Oslo, Noruega

Resumen

Las regiones del norte lidian con baja intensidad solar y bajos ángulos solares, lo que acentúa problemas de salud y bienestar, como problemas para dormir o incluso el trastorno afectivo estacional (TAE). En consecuencia, muestra la urgencia de un sistema de iluminación artificial que pueda respaldar la deficiencia de luz solar y abordar los problemas de salud. Además, los datos de simulación de luz solar verídica aún son escasos, pero han mostrado implicaciones positivas para las personas, de acuerdo con otras referencias. Este artículo comprende la primera parte de un experimento en Obos Living Lab en Oslo, Noruega. Utiliza un prototipo que propone simular la luz natural y evaluar los impactos potenciales en los sujetos. Mediante el seguimiento de un grupo de participantes, se realizaron una serie de cuestionarios, teniendo en cuenta la percepción del usuario sobre el espacio experimental. El enfoque principal estuvo en la luz y la atmósfera generada por el prototipo. A través de parámetros como los niveles de energía y la motivación, fue posible encontrar correlaciones dentro de un marco de tiempo para identificar si hubo mejoras generales e individuales en el bienestar. Los resultados refuerzan la importancia de la luz solar simulada ya que logra efectos psicofisiológicos positivos en los individuos. Por lo tanto, el prototipo podría simular la luz solar con una calidad de luz natural.

Palabras clave: simulación led de luz solar; luz circadiana; bienestar; percepción humana

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1. Introduction

Daylight can be understood as a dual dynamic, a predictable one – related to the sun course pattern – and a less predictable that relates to weather. It is known that sunlight promotes positive psychological and physiological impacts on human well-being and health (Kalinauskaite, 2012). This is specifically due to circadian lighting, which the sun is the protagonist in regulating vitals hormones and functions in each one's organism. Hence, some direct effects include the melatonin suppression, pupil constriction, subjective alertness and performance (Andersen, 2017). Consequently, companies have developed systems that ingress natural light inside buildings through fiber optic cabling, as is the case with Swedish Parans and, similarly, with the Japanese Himawari. In like manner, lighting manufacturers have attempted to simulate natural light to obtain the same positive impacts. For instance, CoeLux® reproduces the visual appearance of the sun and the sky and the light distribution of the outdoors. Indeed, when tested, subjects perceived the room's light with the technological system as significantly more pleasant, natural, and attractive. This leads to the belief that there is a possibility of positive long-term psychophysiological effects. However, since the test only lasted for an hour and the system provided a static cloudless sky, it may influence the perception of the passage of time in space for longer exposures (Canazei et al., 2015). Nevertheless, a study has shown that positive perceptions can be stimulating enough for the brain even if it understands only as a simulation (Sosa Domínguez, 2016).

As a result, the recent introduction of Healthy Hybrid Lighting (HHL) aims to promote the well-being of users in poorly lit areas through a hybrid system capable of blending artificial and natural light to reflect the outdoors experience. In other words, it can catch and transport natural light through fiber optics cables and produce additional artificial light (LED technology) when necessary. Hence, it instantly simulates the quality of natural light. The system comprises three main parts: the solar collector, the transmission of light through fiber optics, and the emission of HHL light (Muros Alcojor & Perdomo Cruz, 2021). In particular, this paper will only consider a partially built system functioning only as a sunlight simulator lamp.

A recent study concerning the perception of daylight from a qualitative perspective highlighted the importance of such assessment since most studies focus on the light's functionality, performance, and efficiency and neglect the human experience. Also, it demonstrated that only 7% of the studies were conducted on residential spaces, and another 2% were in higher latitudes than 60°N (Vikberg et al., 2022). As a result, it excludes the Nordic population that could potentially benefit from technologies such as sunlight simulators.

For this reason, this study is focused on a quantitative and qualitative experiment conducted on a residential building in Oslo, Norway, not only because the knowledge of the effects of simulated natural light is limited but also to test the impacts of the system in regards to the mood and well-being of individuals.

2. Method

The experiment includes quantitative analysis (surveys and questionnaires) and qualitative (interviews). Initially, interviews were conducted in November, during the day, to gather personal information and the habits of the participants, called Inquiry 01. Moreover, in January, the lighting personalization called "dependent variables" was installed so the participants could report their experience anytime of the day, through a mobile application on Inquiry 02. Therefore, in March 2022, an online questionnaire (Inquiry 03) was available uninterruptedly to all residents mainly to assess the people's perception of the Garden's environment, the characteristics of the light, and the effects generated on the atmosphere. Finally, in May 2022, the qualitative analysis (Inquiry 04) took place in Oslo, during the morning, with the participants to measure mainly parameters such as sleep, energy

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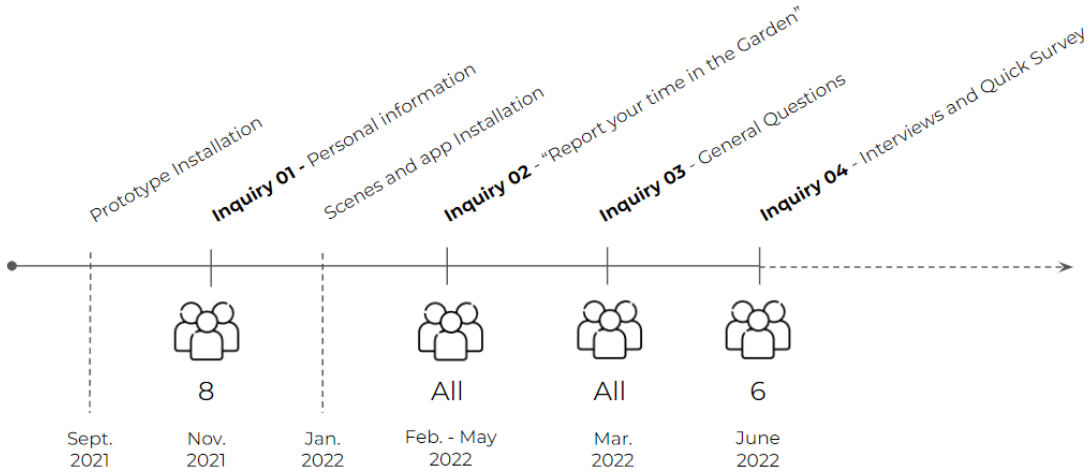
levels, performance, motivation, and well-being. Besides the frequency of use in the Garden and other questions oriented to the use of the prototype.

This methodology will allow comparison within a time frame and find correlations between the usage and general improvements in an individual's well-being (Figure 1). This article will publish results until the completion of Inquiry 04, and complimentary data analysis should be published soon after the experiment is finished.

Figure 1. **Experiment Timeline**



Source: Elaborated by authors, 2022.

2.1 *Experiment*

- *Location*

The experiment will be conducted inside Obo's Living Lab, a 34-apartment block located in the region of Vollebekk in Oslo, Norway. It is located at 10.75° E, latitude 59.93° N (Matusiak,1998).

- *Climate*

The city has a Baltic semi-continental climate which indicates an average temperature for the coldest month of -3.8 °C while the average temperature for the warmer month is 17.2 °C. In addition, in July, the sky is partly clear 52% of the time; on the other hand, in November, the sky is 70% of the time, mostly overcast (Weather Spark, 2022).

- *Participants*

Currently, an average of 65 people live in the building. Among these, initially, 8 were participants in the experiment as volunteers and are under the criteria of "healthy individuals" without any severe medical condition. By Inquiry 04, the number of volunteers was reduced to 6 individuals due to force majeure. They are commonly addressed as either the target group or the experiment participants, they received a frame of suggested use for the experimental space. Meanwhile, all residents can freely use the space and will be assessed solely on Inquiries 02 and 03.

- *The Experimental Space*

The "Garden" is a 4.55m x 3m (14.92ft x 9.84 ft) space located on the first floor at the center of the Obos Living Lab building. Furthermore, the space is part of a communal zone of the building, close to the study room and the main entrance. Some characteristics include the presence of plants and chairs and the lighting prototype fixed at the ceiling with a nearby window façade to the exterior

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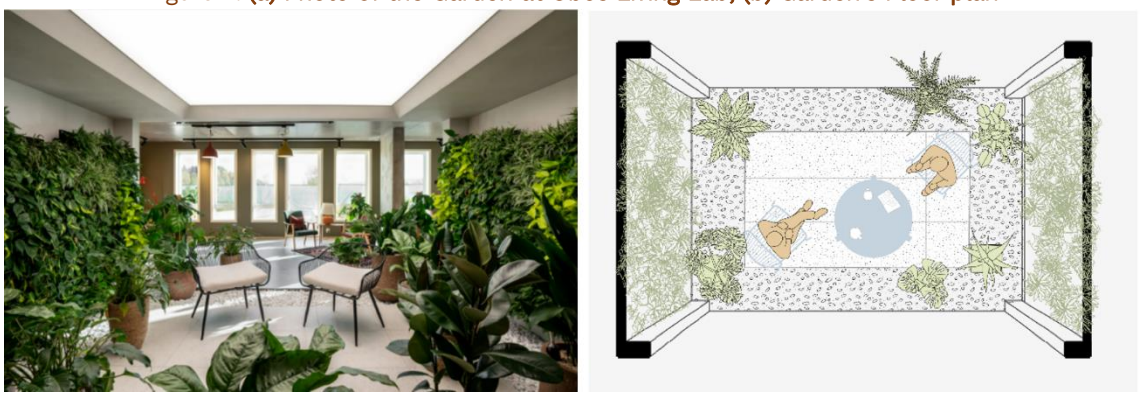
(Figure 2). Incube Lighting, a Norwegian office, developed both the prototype and the choice of materials, textures, and plants by considering the promotion of a natural ambiance. Regarding the greenery, various colors, sizes, and shapes for each plant were selected as it was expected to increase the feeling of the outdoors.

Figure 2. **(a) Photo of the Garden at Obos Living Lab; (b) Garden's Floor plan**



(a) (b)

Source: (a) Photo from Incube Lighting, 2020; (b) Plan by authors, 2022.

2.2 *Lighting System*

The lighting system is composed of 4 modules called Lightbox measuring 1.2m x 1.2m (3.93ft x 3.93ft) each, a total surface of 2.4m x 2.4m (7.87 ft x 7.87ft). Developed by SAKMA Electronica Industrial Sa in Barcelona as a partnership between TEL (ETSAB) and Incube Lighting, which resulted in the experiment's prototype.

The lighting technology follows the recommendations from the Human Centric Lighting (HCL) in order to make light an imperceptible way to potentially modify the mood and well-being of the residents. For the sake of the experiment, the system is partially built, which means it functions as an emitter of light, a LED luminaire. The characteristics of the luminaire are the following: lamp power between 52W and 104 W, CRI 90, SMD LED from 2700 K to 6500 K, with uniform light distribution.

In addition, it functioned in a stable configuration until the release of Inquiry 02, in February. Afterward, participants were able to modify the lighting scenery to the most suited, defined as "dependent variables" below. In particular, aided through two mobile applications (Smart Life Dimmer and Casambi). The participants could manipulate the light in terms of brightness for the first application or choose a pre-determined scene (noon, sunrise, or sunset) for the second application.

- *Procedure and dependent variables*

Specific instructions were given to the participants for proper usage of the mobile applications and correspondent manipulation of the prototype's light. Eventually, by the time the manual mode was available – from February onward - the Casambi application could simulate configured scenes (Sunrise 60s; Sunset 60s; Static 08h; Static 12h; Static 14h, Cloud.) whenever there is a device connected to the internet network. Meanwhile, the Smart Life Dimmer could be used to manipulate the lamp's brightness, giving more independence and customization to the experiment participants. All lighting scenes were updated during the experiment, which doesn't allow analysis within a scientific method. However, future investigations should include the specificities of each and their corresponding user acceptability.

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2.3 Inquiries

The experiment is organized between four Inquiries, each with a specific focus. Details will be explained in the following.

- *Inquiry 01 "Personal Information"*

Regarding the first Inquiry, the interviews were conducted in November (2021) for all experiment participants, a total of 8 people. The goal was to extract only personal information data to establish a general volunteer profile.

- *Inquiry 02: "Report your time in the Garden"*

Regarding the second Inquiry, all residents from the Obos Living Lab could answer an online report through a QR code available in the Garden. Since this Inquiry is uninterrupted, it will be available until the end of the experiment. Indeed, since the participants have free access to the experimental space, reports were gathered all day long, without considering whether the outside daylight coming from the nearby room influenced the answers. In addition, the prototype's light could be manipulated, which utterly affects the general lighting for each report according to the pre-determined scenes. Hence, data analyzed for this article were gathered from February 17th, 2022, until May 17th, 2022, summing up 50 entries.

The question about mood state was based on Psychologist Robert Plutchik's wheel, and it identifies eight primary emotions as a foundation of many others that are more complex. Meanwhile, the goal of the questions was related to their time spent in the Garden. This means that questions were on: how long they stayed in the experimental space, which setup mode was used, the feeling and mood state at the moment, description of the light, and how they would rate the importance of having a Garden.

- *Inquiry 03: "General Questions"*

Regarding the third Inquiry, in March 2022, a set of 36 general questions were asked online through OBOS in Norwegian to all residents at Obos Living Lab. Hence, participants answered the inquiry through a personal electronical device, at a desirable time and space. Which means that the experimental space was not actively used. Nevertheless, questions were addressed to the experience had in the Garden and related to the lighting prototype. There were three main themes for the questions: the Garden's environment concerning the building, the Garden's light, and the Garden's atmosphere.

Firstly, the study aimed to understand how each individual evaluated the importance of the Garden, considering the communal areas and the activities linked to the use of the experimental space. Subsequently, participants were asked to define the characteristics of the prototype's light according to an eleven-point Likert Scale ranging from "not at all" to "very" applied in terms such as "Artificial," "Bright," "Soft," and so on.

The choice of words was based on a study (Canazei et al., 2017) that used bipolar rating scales to define the characteristics of light (for example, artificial and natural). Moreover, the residents were asked to rate their feelings after spending time in the Garden according to the same eleven-point Likert Scale applying terms such as "Surprise," "Inspiration," "Discomfort," and others in order to define the atmosphere-related effects as also in accordance with the emotion types from another reference study (Desmet, 2012).

In addition, one question about the connectedness to the exterior whenever experiencing the Garden. Lastly, the final set of questions aimed at the perception of social interaction, creativity, mood state, and well-being regarding the Garden. The mood states were based on the eight basic emotions defined by a functional framework (Plutchnik, 2001).

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- *Inquiry 04: "Interviews and Quick Survey"*

Regarding the fourth Inquiry, completed in June 2022, individual interviews were scheduled during the morning in the Garden with the target group and organized into two parts. Firstly, it is asked for the interviewee to answer multiple-choice questions from the Quick Survey through a tablet device. The Quick Survey aimed to assess the frequency of use, habits, and activities involved with the Garden and the well-being. Indeed, some questions were repeated purposely to evaluate the consistency of responses, while others were compared with the answers previously obtained from Inquiry 01. Furthermore, the second and last part were open-ended questions as a form of an interview. Questions were focused on sleep, energy levels, performance, motivation, and well-being.

One study was used as a reference during development (Jovanović et al.,2014), while questions were verbally anchored using a five-point scale to express satisfaction and preferences, being "one" unimportant and "five" very important. In addition, it was also based on the questionnaire from a study on patients interned at an Intensive Care Unit (ICU) experiencing circadian light effects (Engwall et al., 2015). To conclude, some questions were asked regarding the prototype, the mobile applications, and final insights for internal control of the research group.

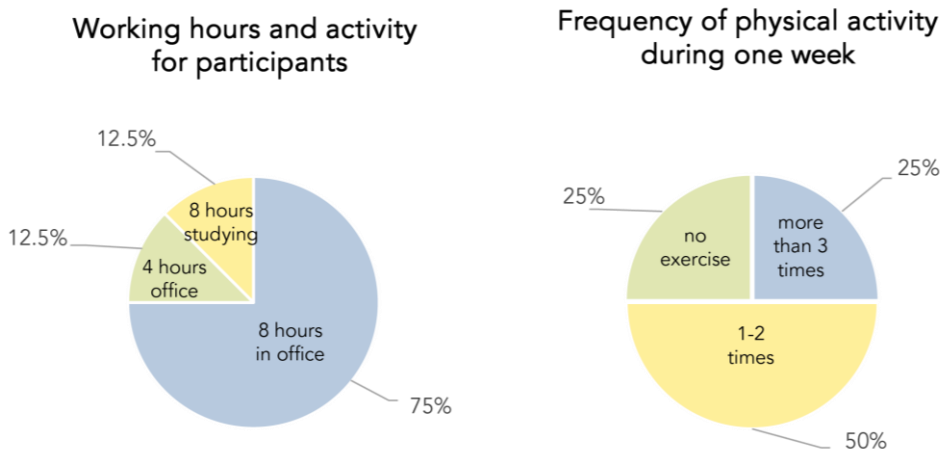
3. Results

Results from all four Inquiries were computed and are summarized in the following.

3.1 Results Inquiry 01 "Personal Information"

The topics of the first inquiry include questions such as employment, physical activity hours, gender, educational level, existence of children, age group distribution and family situation. Most of the experiment´s participants work an 8-hour routine (75%), half (50%) sleep between 7 to 8 hours and exercise from 1 to 2 days a week as seen on Figure 3.

Figure 3. **Volunteer's Activities**



Source: Elaborated by authors, 2022.

Meanwhile, results show that the experiment has a total of 8 subjects, all Norwegians, with equal gender distribution, the majority with a Master's degree (62,5%), and no children (75%). Also, participant's age group ranged mostly from 30 to 40 years (37,5%) and from 50 to 60 years (37,5%). And the family situation was mostly marked as single (37,5%) as seen on Figure 4.

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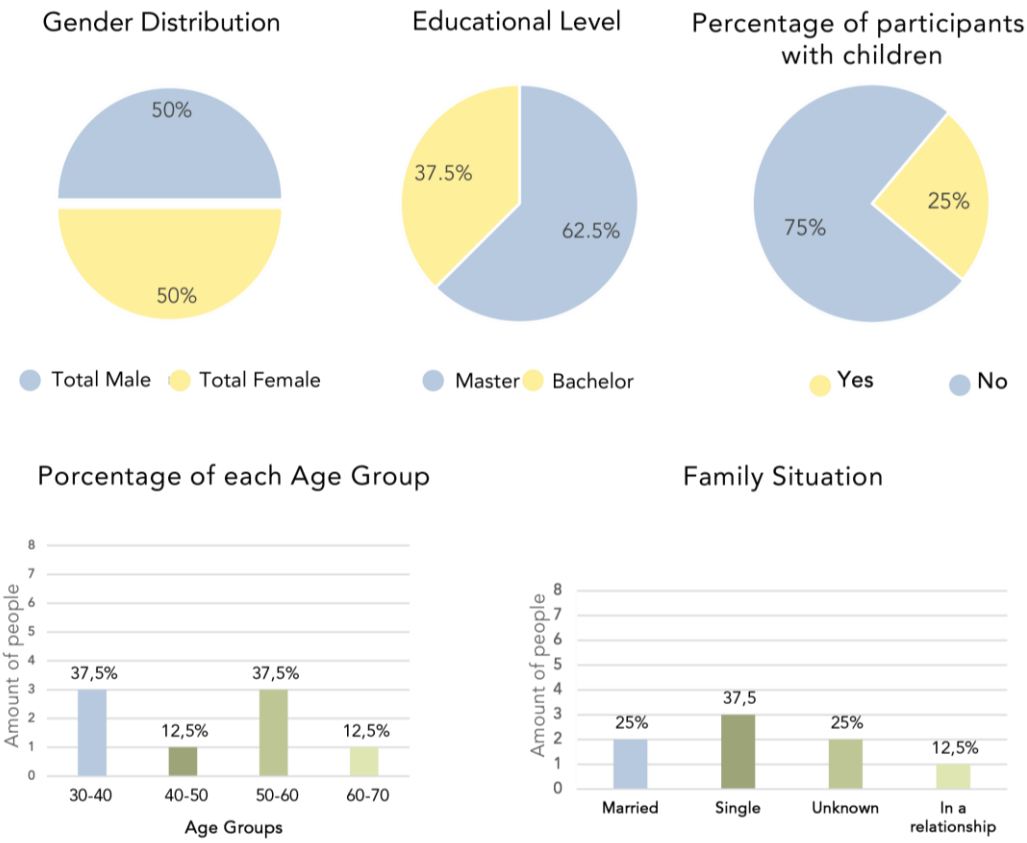
Figure 4. **Volunteer' Profile**

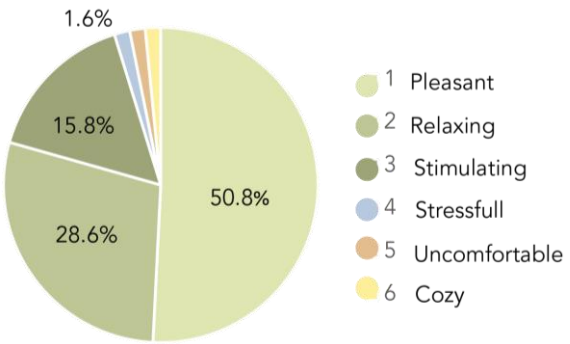


Source: Elaborated by authors, 2022.

3.2 *Results Inquiry 02: "Report your time in the Garden"*

As far as the results from Inquiry 02, among all the 50 entries that were submitted to the online report during the 2-month period, the words mostly used to describe the Garden's atmosphere (Figure 5) were "Pleasant" (50.8%), "Relaxing" (28.6%) and Stimulating (15.8%).

Figure 5. **Percentage of words most used to describe the Garden's atmosphere**



Source: Elaborated by authors, 2022.

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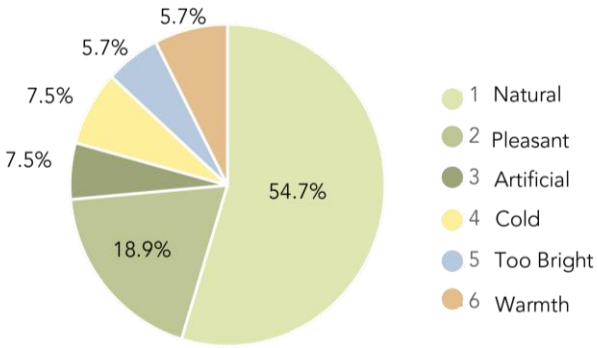
Also, the words mostly used to describe the Garden's light (Figure 6) was "Natural" (54.7%) and "Pleasant" (18.9%).

Figure 6. **Percentage of words most used to describe the Garden's light**

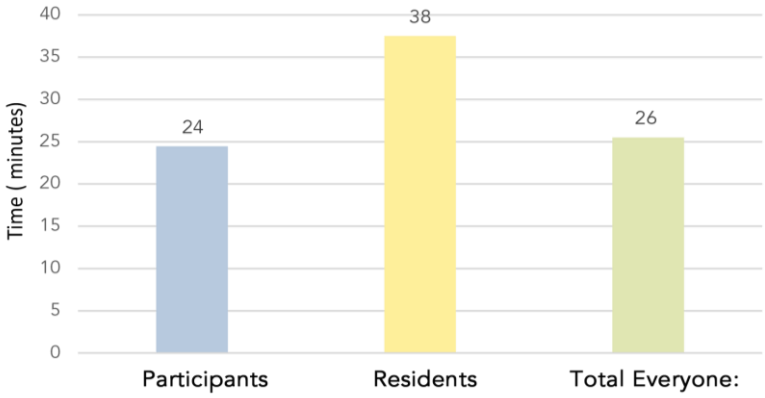


Source: Elaborated by authors, 2022.

Furthermore, the average time spent in the Garden was compared between the participants, residents, and the total (Figure 7). The experiment participants registered between the three months of evaluation an average of 24 minutes for each use.

On the other hand, the residents showed an average time of 38 minutes for each use. As a result, an average of 26 minutes were spent in the Garden, considering all of the residents of the Obos Living Lab. Nevertheless, 92% of the entries were from the participants, while only 8% were from the others residing in Obos Living Lab but not actively participating in the experiment.

Figure 7. **Average time spent in the Garden (minutes)**



Source: Elaborated by authors, 2022.

In addition, when comparing the correlation between times spent and the feeling reported for each entry, there is a clear predominance of "Relaxing" and "Pleasant" during the first 30 minutes. After that, in less quantity, "Pleasant" and "Stimulating" predominate, as seen on Figure 8.

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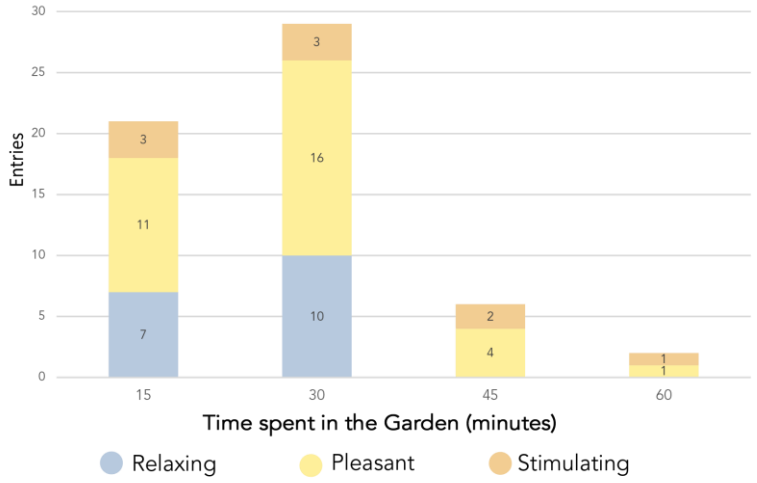
Figure 8. **Correlation between feeling reported, time spent in the Garden and number of entries**

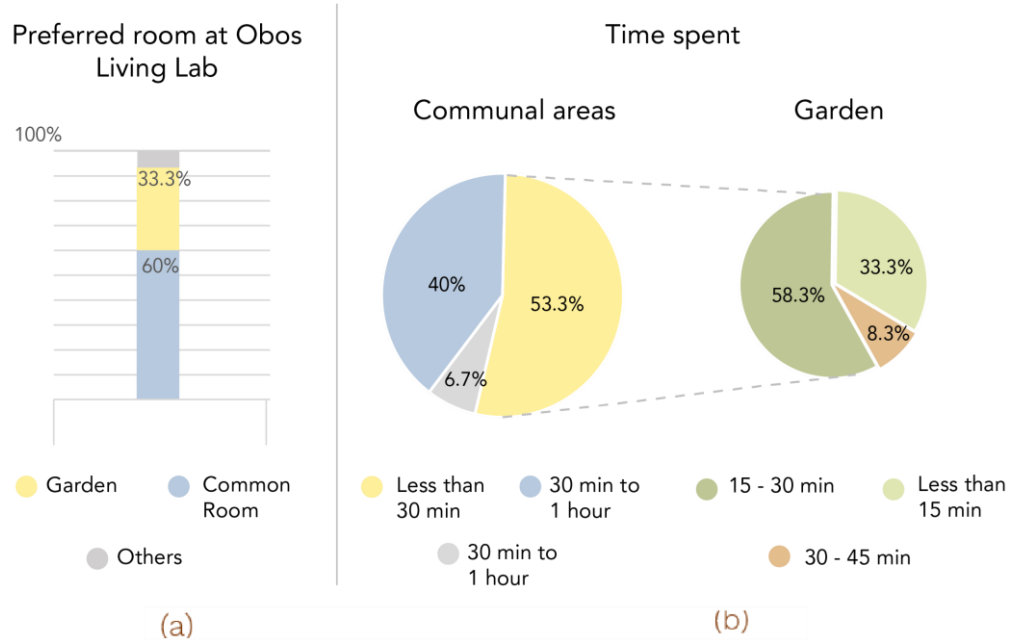


Source: Elaborated by authors, 2022.

3.3 *Results Inquiry 03: "General Questions"*

Results from Inquiry 03 suggests that the Garden may be considered a significant preference space at Obos Living Lab. Data shows that 33.3% of the general residents chose the space as their preferred room (Figure 9). In like manner, the Common room corresponded to 60% of the answers. Meanwhile, also according to Figure 9, the average time spent in the communal areas is less than 30 minutes (53.3%) and the average time spent in the Garden is between 15 and 30 minutes (58.30%). Hence, it shows that most of the time spent in communal areas is spent in the Garden. Also, the time of the day when the Garden is mainly used is before dinner (41.7%).

Figure 9. **Graphs about the preferred room and Average time: (a) Preferred room at Obos Living Lab (b) Average time spent on communal areal and Average time spent in the Garden**



Source: Elaborated by authors, 2022.

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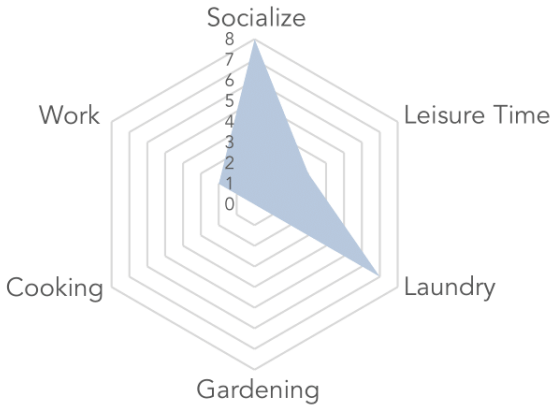
Furthermore, social interaction is prevalent when analyzing activities mainly done in the Garden (Figure 10). Another example would be that 84.6% confirmed that the furniture of the Garden allowed social interaction, even if all (100%) suggested improvements.

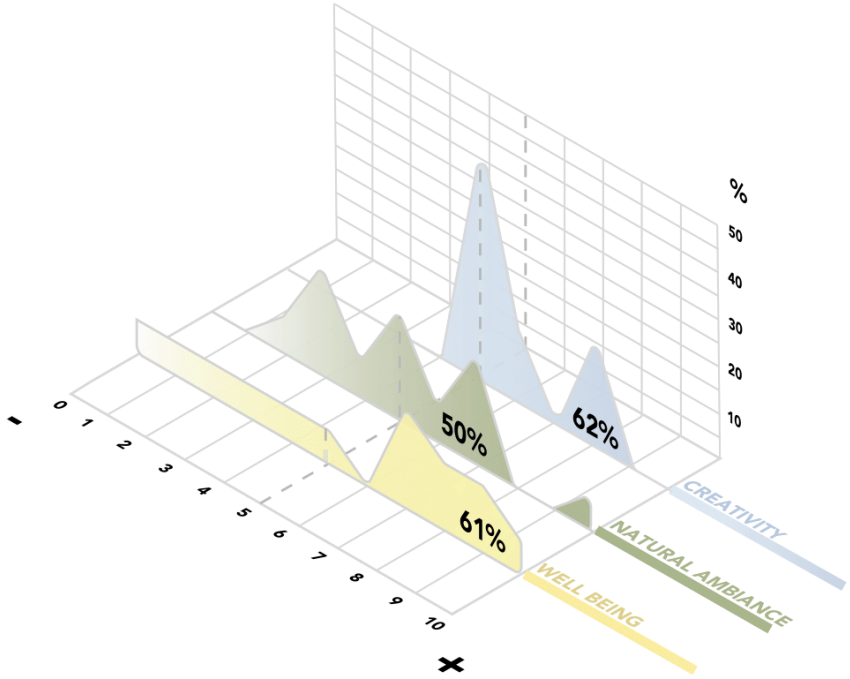
Figure 10. **Activities mostly done at Obos Living Lab by the residents**



Source: Elaborated by authors, 2022.

Afterwards, when subjects were asked about their perception of improvements in their "Well Being" and "Creativity," results show that majority valued them positively (Figure 11). As revealed by the 61% for "Well Being" and 62% for "Creativity." On the other hand, "Natural Ambiance" which means the feeling of the outdoors or in other words, how connected to the exterior one person would feel, was valued neutrally at 50%. This shows inconclusive result for such parameter.

Figure 11. **Perception of improvements on each category. Parameters: Creativity, Natural Ambiance and Well Being**



Source: Elaborated by authors, 2022.

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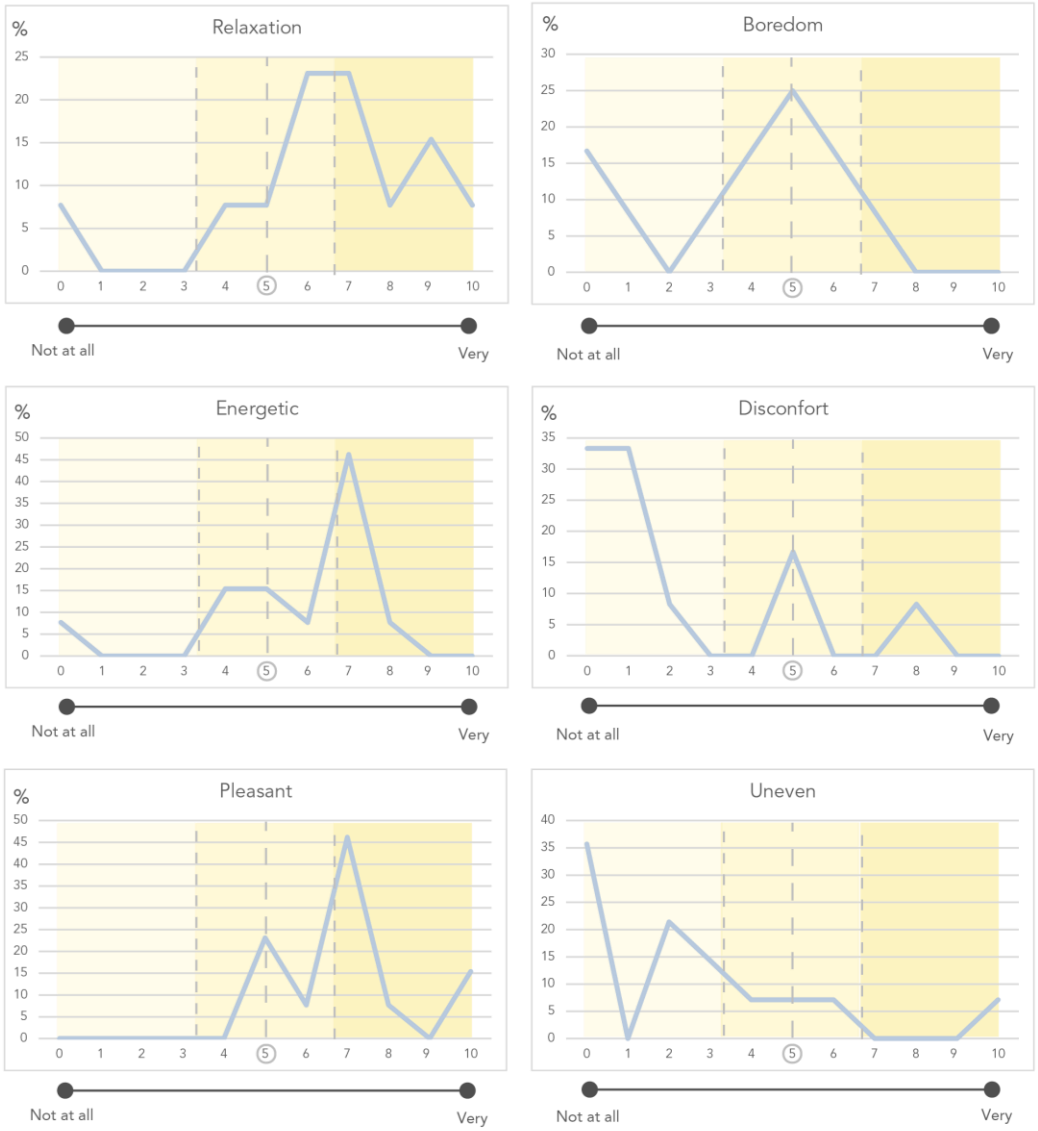
As far as the rating of characteristics and feelings commonly associated to the Garden, results demonstrate a pattern. For instance, it resulted in higher values for words that had positive connotations and lower values for negative ones. For example, “Relaxation,” “Energetic,” and “Pleasant” had mean values of 6.46, 5.69, and 7.00, respectively, all above average of intensity (5). Meanwhile, “Boredom,” “Discomfort,” and “Uneven” had mean values of 3.54, 1.85, and 2.84, respectively, below the average of intensity (Figure 12). In the same way, it usually resulted in medium values for neutral connotations.

Figure 12. **Rating of characteristics and feelings assigned to the light of the Garden (From 0 to 10 / From Not at all to Very)**



Source: Elaborated by authors, 2022.

Lastly, the concept of mood state was addressed in a question that showed that 90,9% of the residents chose “Joy” as the primary emotion felt after experiencing the Garden (Figure 13). Similarly, the rating of the importance of having natural light in living environments was significantly high, with a mean value of 7.42 (out of a total of 10), indicating the presumption of “very important” as according to the scale (Figure 13).

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Figure 13. **(a) Mood state: (b) Rating on the Importance of having Natural Light**

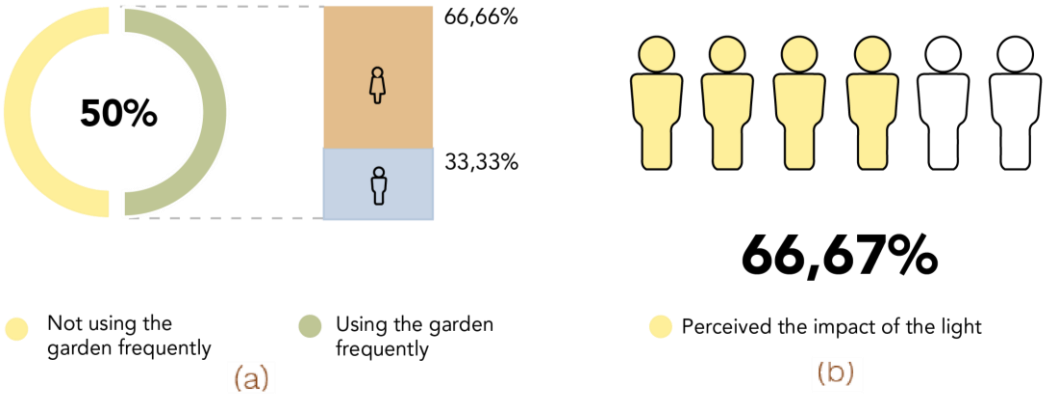
Source: Elaborated by authors, 2022.

3.4 *Results Inquiry 04: "Interviews and Quick Survey"*

It was observed from Inquiry 04 that 50% of participants were frequent users of the Garden, 66,66% female and 33,33% male (Figure 14). As a matter of fact, it might contribute to the 66,67% of individuals that could perceive the impact of light, also according to Figure 14.

Whether positive, such as the feeling of "freshness, energetic, stimulating, relaxed" (during the morning) or negative, when exposed to the light in the afternoon, as described verbally by the interviewed subjects. Similarly, the same percentage (66,67%) of individuals felt the need to increase the time spent in the Garden.

Figure 14. **(a) Participant's frequency, Gender Distribution; (b) Percentage of participants that perceived the Impact of Light (right)**



Source: Elaborated by authors, 2022.

Regarding the preferred room of the Obos Living Lab, data in Figure 15 shows a clear preference for the Garden (83.3%) with a predominant frequency of use from once to 4 times a week (83,3%), usually at the afternoon (50%) for around 15 to 30 minutes (50%).

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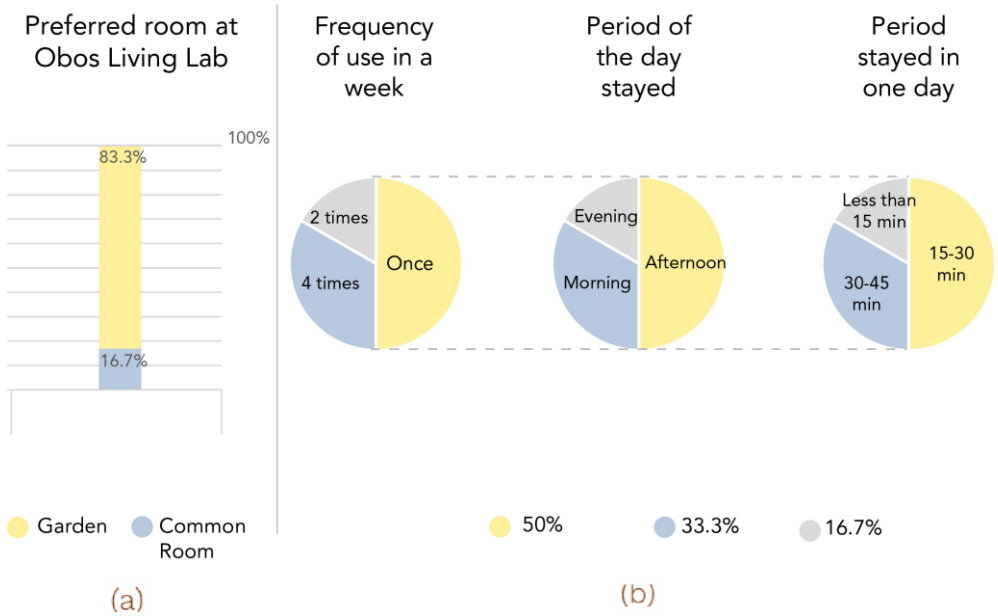
Figure 15. **Preferred room at Obos Living Lab and Participant's frequency in the Garden**

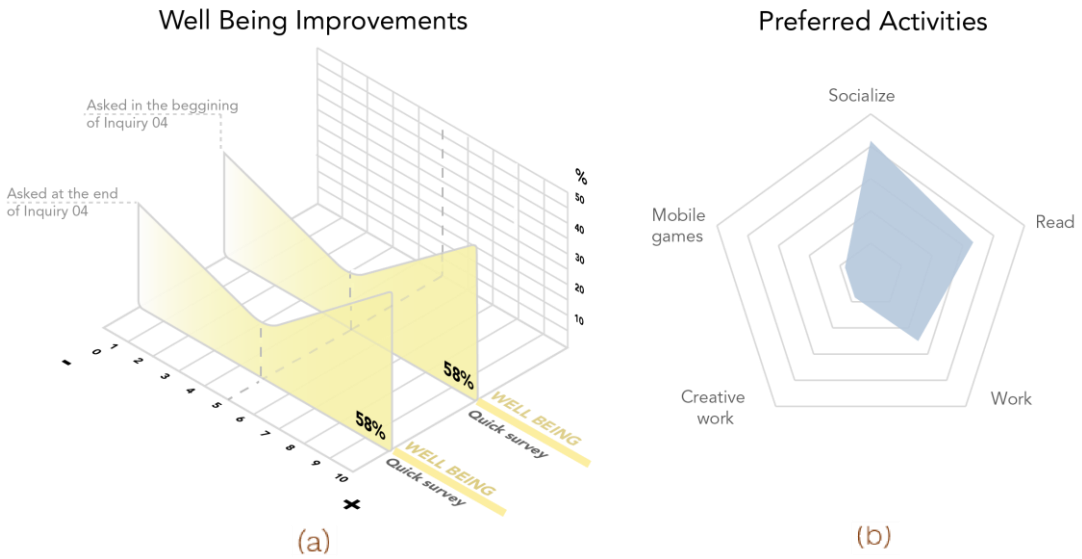


Source: Elaborated by authors, 2022.

The perception of improvements in participants' Well Being shows that 58% of the answers valued this parameter above average. In other words, in an eleven-point Likert Scale, most answers were from 5 to 10, which indicates a positive response.

This parameter was asked two times, to check validity of answers, both moments showed a result of 58% of people that perceived positive effects in the well-being. In addition, the main activity performed in the Garden by the residents was considered to be "Socialize" (83.3%), followed by "Read" (66.7%) and "Work" (50%) (Figure 16).

Figure 16. **(a) Perception of improvements on Well Being; (b) Activities mostly done at the Garden by the residents**



Source: Elaborated by authors, 2022.

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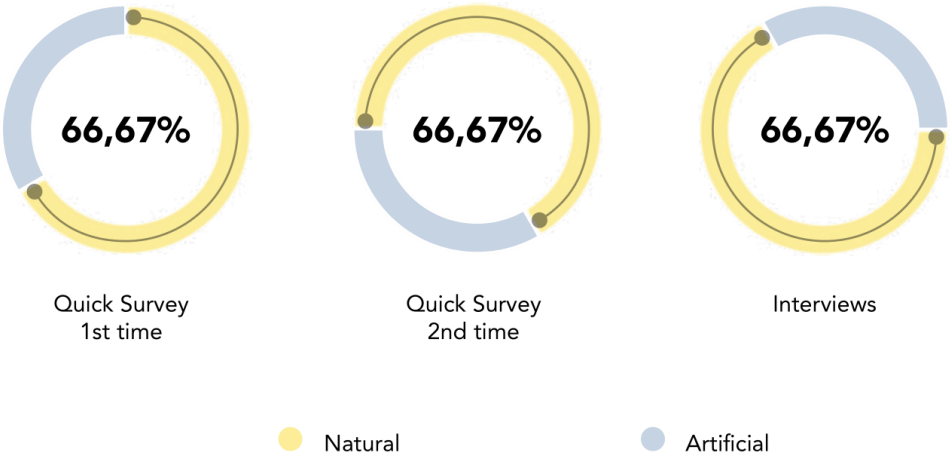
Notably, regarding the characteristic of the prototype's light, if it was either "Natural" or "Artificial," the question was asked three times during Inquiry 04 to see the results' validity. It suggests coherence since it showed a consistent response, as shown on Figure 17. After all, around 66,7% of the experiment participants perceived the Garden's light as "Natural."

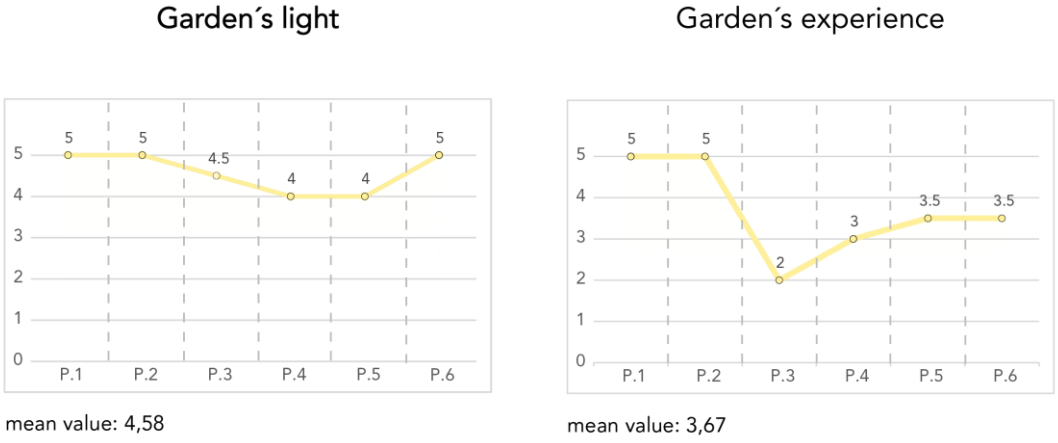
Figure 17. **Percentage of participants that perceived the light of the Garden as Natural/Artificial**



Source: Elaborated by authors, 2022.

All participants (100%) believe the community values the Garden positively as well as the presence of greenery. Since it was also verbally mentioned between all the participants. To conclude, the satisfaction rate of the target group on a five-point Likert Scale regarding the light and the experience of the Garden showed a mean value of 4.58 and 3.67, respectively (Figure 18). As a result, it demonstrates a positive outcome since it is above average (2.50) for both parameters.

Figure 18. **Satisfaction rates**



Source: Elaborated by authors, 2022.

4. Discussions

When dealing with an investigation about light, it might be expected from the reader that the exterior light could play a significant role during the assessments. However, not only the experimental space had a distinguish light of its own, as produced by the prototype but also it could have varied lighting scenarios. For such reason, there wouldn't be enough data in order to correlate exterior daylight from the nearby room and the lighting scenes from the prototype. In addition, it does not meet with the

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main goals of the research, which is the simulation of sunlight and its possible positive effect on people. With that being said, in the following paragraph it will be explained the lack of relationship between exterior and interior light in each inquiry.

In the first Inquiry, only demographical information of participants was collected, excluding anything about the light. Then, Inquiry 02 considered reports collected during a 2-month period during all day long. Each report stated whether it used a static or a pre-determined scene. However, it did not mention the exterior weather conditions. Later, Inquiry 03 was assessed online and could be answered at the most suited time and space for the participant, which means that it was not assessed in the Garden. Nevertheless, Inquiry 04 was concluded in the experimental space but participants were expected to answer according to the past months of use. Therefore, it represented their memory of the experiences obtained.

Similarly, the light scenes from the prototype were evaluated by the participants in Inquiry 02 and 04 which allowed the enhancement and detection of adjustments during the process. For instance, it increased the time duration of the scenes and instead of using a combination of applications it is under process a single application. This way, further investigation will have a greater focus on the light scenes as it will be able to design a scientific method to do so. Also, until now, only the participants have had the ability to manipulate the prototype, so there is an intent on allowing all residents. Hence, increasing further investigation's sample size.

Another aspect was the scale bars, questions from Inquiry 03 about attributing intensity of characteristics and feelings for the light were initially designed in a five-point Likert Scale. On the other hand, when executed, it went to an eleven-point Likert Scale. For this reason, it is believed that it might confuse the residents because participants that marked the lowest value (0) leave a margin to believe that they either mean" not at all" at its highest magnitude or were unsure what to inform. Since the numerical zero often denotes the absence of quantities and magnitudes.

Another issue perceived was that most residents would use the Garden before dinner. Since only the experiment participants had access to the mobile applications to change the prototype's light, it might indicate a high chance of people using it with improper lighting. That means going on the contrary of assisting in their regulation of the circadian rhythm. Indeed, it probably influences them to use the Garden and the light less often. Consequently, for the upcoming phases of the investigation, the research group will ensure all residents have access to the personalization of the light from the prototype.

Furthermore, the Garden is believed to have a strong social connotation, often described as "the heart of the building" or "the star of the building" indicating an overall content from the community. As verbally anchored by the interviews (Inquiry 04), the complaints were about the furniture, which is in coherence with the main activities developed in the Garden, socializing and reading. Thus, favorably indicating the change of chairs for more comfortable ones, a change of table, and allowing the possibility of closing the space.

5. Conclusions

This study investigated the effect of an artificial lighting system that intends to simulate natural light in a residential facility. The prototype's light was constantly associated with positive qualities and feelings, in order of significance: Pleasant, Relaxation, Safe and Natural. Therefore, coherent with the high satisfaction rate and the participants' mood state, mainly linked with "Joy."

Simulations suggest that participants could positively ensure slim benefits of improvements in perceived well-being and creativity. Although the perception of connectedness to the exterior did not necessarily improve, there is evidence to believe that the plants help to induce a natural ambiance, positively affecting the Garden experience.

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Indeed, the analysis identified the experimental space as a significant room in the Obos Living Lab's structure, possibly also encouraged by the social aspect. In particular, the findings show a strong correlation between light and the physical space. Fact sustained by the interviews when subjects showed difficulty separating such elements of what is considered to be the experience as a whole, which also resulted in a high satisfaction rate. For example, the plants were mentioned in all (100%) interviews as essential since the perception that surrounding plants were thriving usually positively impacted the individual's well-being. In contrast, the opposite is also true, as it was stated that it affected them negatively. Another example was that greenery could influence participants to grow their own plants in the Garden.

In addition, results suggest that the prototype can plausibly simulate sunlight with a natural quality of light. In other words, it favorably indicates the relevance of the lighting system for beneficial psychophysiological effects. Moreover, data leads us to believe there is a correlation between time spent in the Garden - the frequency of visits to the Garden - and the perception of the well-being of individuals. For example, in order of significance, the Garden's atmosphere is considered Pleasant, Relaxing, and Stimulating. Also, mostly regarded as Pleasant and Relaxing during the first 30 minutes and Pleasant and Stimulating from 30 to 60 minutes.

To conclude, all volunteers regarded having natural light in the living environment as highly important. Generally, each would spend around 30 minutes in Communal areas and from 15 to 30 minutes in the Garden, with a frequency of visits of approximately 4 times a week. In terms of health improvements, there was a specific improvement in one of the volunteers' sleeping habits. Therefore, a future assessment will be made for further conclusions to evaluate in the long term. Nevertheless, it indicates the prototype's relevance and the need for further analysis of other potential benefits.

Authorship

This paper is also part of the first Author's master thesis. Meanwhile, the second author is an advisor of the thesis and have revised it critically for important intellectual content. Finally, the third author is a collaborator that represents Incube Lighting, and has collaborated in the execution of the lighting prototype in the garden and the preparation of surveys and data collection for subsequent analysis. in addition to being responsible for all the communication and logistics that is done directly in Oslo, both with the building owners and with the volunteers.

Conflict of interest: Author declares no conflict of interests.

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