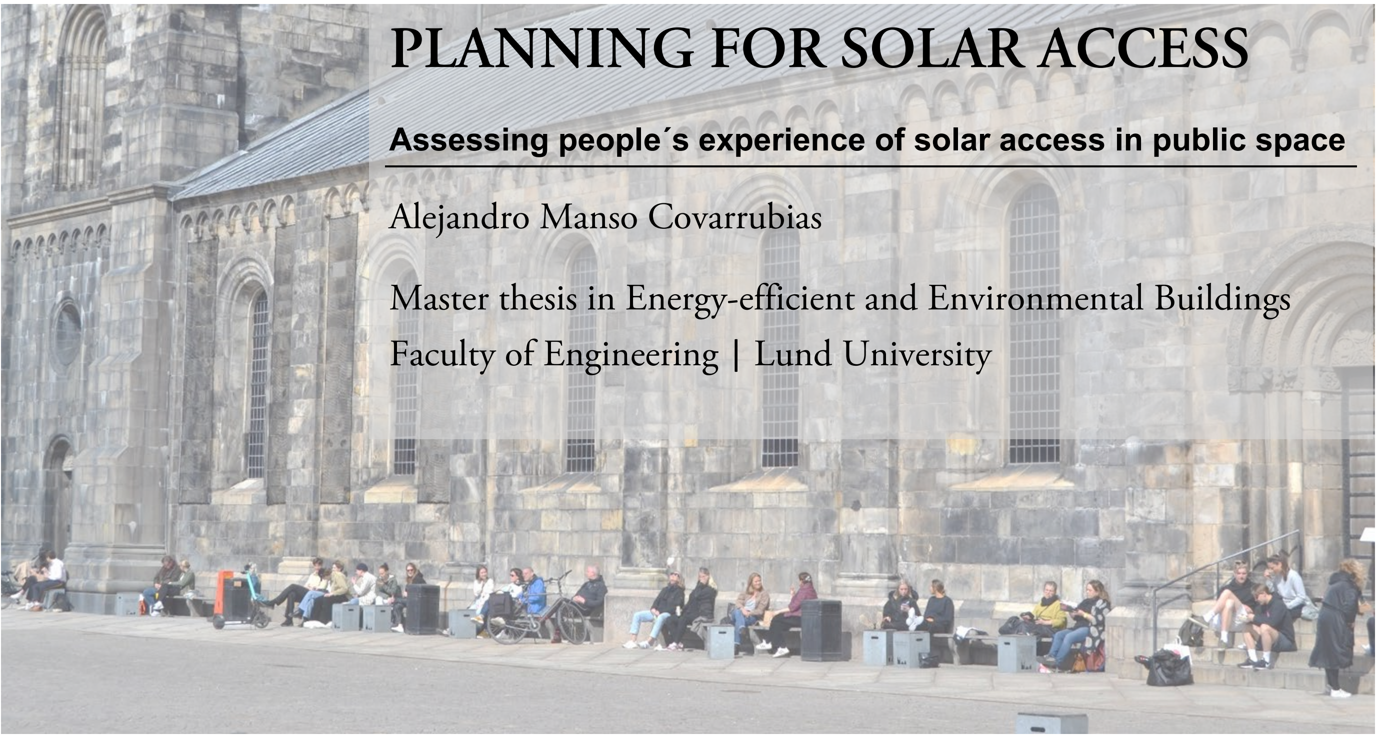

PLANNING FOR SOLAR ACCESS

Assessing people´s experience of solar access in public space

Alejandro Manso Covarrubias

Master thesis in Energy-efficient and Environmental Buildings

Faculty of Engineering | Lund University

Lund University

Lund University, with eight faculties and a number of research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 112 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 6 000 employees and 47 000 students attending 280-degree programmes and 2 300 subject courses offered by 63 departments.

Master Programme in Energy-efficient and Environmental Building Design

This international programme provides knowledge, skills and competencies within the area of energy-efficient and environmental building design in cold climates. The goal is to train highly skilled professionals, who will significantly contribute to and influence the design, building or renovation of energy-efficient buildings, taking into consideration the architecture and environment, the inhabitants' behavior and needs, their health and comfort as well as the overall economy.

The degree project is the final part of the master programme leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

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Abstract

Swedish cities are getting denser. People spend a lot of time indoors, it therefore becomes important to guarantee daylight availability and solar access in buildings, in order to save energy and ensure human well-being. However, this becomes important in the case of outdoor spaces as well. Outdoor spaces can become places that invite people to stay. Thus, spending less time indoors, having as a possible outcome a lower energy demand for heating and air conditioning. Nowadays there are no evidence-based recommendations, nor research-based guidelines to guarantee good daylight within urban spaces. An approach based on the understanding of people's insights meanwhile experiencing the direct sunlight could support the development of these recommendations.

Therefore, this study was carried out using a qualitative approach, based on surveys analyzing people's experience about solar and daylight access in public spaces in Lund and Helsingborg. Additionally, point-in-time technical measurements and observations were conducted to support the surveys. The temporary context of the study was placed around the spring equinox. As an outcome of the study, no correlation was found between the questionnaire results and the level of illumination, although there was slight relationship between illumination and pleasantness under cloudy or overcast days for some respondents. Furthermore, a second survey took place, based on qualitative observations of activities and behavior of space user. The second survey took place in the same locations as previously. This time, the observations occurred during spring weather conditions. It could be observed that people usually choose areas with direct sunlight for activities like eating, reading or hanging out. In this situation, it could be observed that direct sunlight the development of necessary activities like passing by or waiting was considered less important. An outcome of the observations revealed a clear willingness to be more socially active and interact with people under direct sunlight.

In addition, other factors played a minor role, but still they should be considered to be analyzed in future research. Special attention should be put in design stages regarding wind protection and functionality of the space in relationship with the available direct sunlight to maximize the use of public spaces. This research did not include microclimate, which may have a great impact in people's evaluation of solar access in public spaces.

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1 Introduction

1.1 Background

By 2055, around 68 % of the populations will live in cities and urban areas (United Nations, 2018). This is not only a reality in developing countries, where migration occurs from the countryside to the city, but in developed countries as well (Ritchie & Roser, 2018). For this reason, cities are getting denser, with many new buildings and neighborhoods that have been constructed, are under planning or have been integrated into the existing urban fabric.

Sweden in not an exception. With an increase of population of 16 % in the last years from the beginning of the 21st century, many of its urban areas are getting denser. Just in the region of Skåne, a 9 % increase of in terms of population is expected between 2020 and 2029 (SCB, 2021).

In many cases, densification would finally result in a lack of adequate daylight access in buildings and outdoor environments affecting people's health (Bournas & Dubois, 2019) and boost the energy demand in buildings (Strømann-Andersen & Sattrup, 2011). On the other hand, an increased density helps to reduce the use of valuable agricultural land and increases the efficiency of public transportation. However, cities with a low density, resulting in large suburbs in Nordic and North American cities, has its own negative consequences (Gropius, 1955).

Solar access is a key aspect in the transition to low carbon cities. It is related to well-being and other benefits could be the deployment of economic activities, and its potential for renewable energy on site or energy source and stimuli for plants (Dubois et al., 2019). Daylight is extremely important in architecture. Its significance comes from two big aspects to consider: the well-being of its users and energy. Daylight in all its forms improves architectural quality and can create unique space perceptions. Also, some authors mention a positive impact on the efficiency of the occupants (Edwards et al., 2002). Besides, the use of artificial electric lighting is potentially reduced in dwellings (J. C. Lam, 1996), and electric lighting (C.Lam & Li, 1996) and primary energy use (Bodart & De Herde, 2002) are potentially reduced in offices.

Daylight varies in brightness and intensity and carries information about the time of the day, the weather, and the season. This information is crucial for indoor activities and to satisfy our biological circadian clock. Also, people have a preference for natural daylit spaces (Tregenza & Wilson, 2011).

As we spend most of our time indoors (Klepeis et al., 2001) and the hours of light are limited in Sweden in winter, it is important guarantee the availability of daylight and solar access indoors. However, this is important in the outdoor space too. Outdoor spaces can invite people to stay there, and if they keep with human needs, they will be able to attract more people (Gehl & Svarre, 2013). With this, people would spend more time outside, and less indoors, resulting in a lower energy demand for heating or air conditioning. Urban planners should enhance social life in the public space and for this, design spaces where solar access is considered a factor that enriches the quality. Therefore, good solar access would encourage people to use the squares, courtyards, parks, etc. High-quality outdoors spaces help also to better aspects like environment, economy, social relationships and culture.

Designing good cities and buildings becomes necessary and while architects work for this purpose, urban planners' decisions have previously a greater impact on the previous building performance (Kanters & Horvat, 2012). Urban context and building's orientation shape the potential use of daylight and the available solar access (Li & Tian, 2020). These factors should be prioritized already at this moment. From this point, equal possibilities for those living in cities and town should be created. Here is when urbanism and urban planners play a vital role. Most of the people working in urbanism or other professions related to architecture are aware of solar access in the building envelope and the outdoor space. However, nowadays there are no evidence-based recommendations, nor research-based guidelines to guarantee good daylight in urban spaces. An understanding of people's experience with solar access could support the development of these needed recommendations.

There are some regulations nowadays that consider solar access in urban stages. Some of them are old and simple. One of the first documents concerned about solar access was a long time ago, the Athene's letter, where Le Corbusier pointed out in that every house should have at least 2 h of direct sunlight in winter solstice. They already knew the importance of solar radiation for human health (CIAM, 1933). Some regulations, like the British '*Right to light'*, they did incorporate some regulations for solar access ("Rights to Light," 2020). Other countries have only a brief mention of the mandatory use of windows for every bedroom or living room in the urban regulation as the only requirement for daylight, but not directly for solar access (P. Esquivias, personal communication, March 22, 2021).

The Swedish legislation for daylight is mentioned in the daylight in buildings (6:322 *Dagsljus*) and requirements of solar access (6:323 *Solljus*) (BBR, 2020). However, the urban regulations and the response from society are always coming late. Climate and urban growing changes rapidly, and there is still a lack of consensus between politicians, architects, social research that study the city, etc. (Hagan, 2014).

Finally, the society has dealt with a lockdown in many countries and other restrictions during the *Coronavirus Disease* of 2019 pandemic (COVID-19). Because of this, the lack of solar access (among other problems related to the building stock) has been highlighted by those who had been working home. An increase of depression is only one of the problems that these circumstances has developed (Iob et al., 2020). The demand of a more suitable home for home working includes a special attention for balconies or gardens (Mellander, 2020; Norlander, 2020). The real state agencies have noticed these new tendencies also in other countries (Olatz, personal communication, January 23, 2021; E. Sanchez, personal communication, January 21, 2021), where a higher interest has been shown in single family houses with garden, balconies, etc.

Although it is obvious that more and more people now know the advantages of home working (Höglander, 2021) and are planning to search for this in houses with an adequate solar access, this trend in the market could be temporary. It is still not clear how long this trend will last because other sources have investigated and conclude that many people are not satisfied with home working and desire to work in offices with the rest of their fellows for different reasons. This could limit the already mentioned trend in the market (Virgin, 2021).

1.2 Objectives

The present research has the objective to assist urban planners to have a better understanding of solar access in the outdoor space. The research aims to provide basic information about people's evaluation of solar access in a specific context for future studies and future implementation in early design phases.

The main research questions for this study follows:

- How do people evaluate solar access in public spaces and how do they behave under specific conditions for the chosen space?
- How do the evaluation and the behavior relate to the physical solar access?
- Which other factors (function of the space, wind exposure, street furniture, etc.) affect or interfere in the perception of solar access?

1.3 Scope and limitations

The scope of this study is limited to the weeks around the spring equinox, and thus, the results refer only to this season.

Due to the limited time and resources, the investigation was conducted mainly in Lund. The selected spaces for the assessment were limited to a few representative medium size public squares. The survey and the observations were carried out by only one person, resulting in a limited number of samples, measurements and interviews done. Moreover, the lack of tools limited the possibilities of carrying out microclimate measurements as wind speed.

In light of the current COVID-19, there could be some limitations when surveys were carried out. A request for exemption and a risk evaluation were necessary before the survey, as well as some precautions during this. Fortunately, most of the people in the streets accepted to participate in the survey regardless the pandemic.

1.4 Theoretical background

In general, there is a rather large body of literature regarding user preferences and activity patterns in cities, as well as some outdoor thermal comfort studies. But there are only a few investigations on exterior spaces regarding daylight.

De Regt and Deak (2019a) collected 25 sites in different cities among outdoor spaces like streets, squares, courtyards and parks for a research in 2019. First, they simulated those sites for different metrics like Daylight Autonomy for 2 500 lux, continuous Daylight Autonomy for 10 000 lux, sky view factor, annual illuminance, sunlight hours and average illuminance values. Secondly, a questionnaire-based interview for users of those urban spaces collected data about the user experience of the site. A correlation and a regression analysis were conducted to find a relationship between responses and qualitative impressions with the quantitative data from metrics. One of the goals was to create benchmarks for later building or urban planning projects using the metrics to search for desired daylighting qualities of new outdoor spaces. They found good correlation between people experiences and some spaces from where it was extracted that daylight analysis could be more subjective for spaces like courtyards, parks and squares than along streets according to user preferences. They also found that their methodology may be used in daylighting in outdoors spaces. Daylight Autonomy 2 500 lux was a useful metric for plant growing meanwhile continuous Daylight Autonomy was the most appropriate for user experiences.

Others have studied energy performance at an urban scale, for example, the context and urban density affecting the performance of low-energy buildings. Strømann and Sattrup discovered an impact up to +30 % and +19 % in energy consumption for offices and dwellings respectively in northern Europe (Strømann-Andersen & Sattrup, 2011). The transcendental role of the geometry of the urban canyons was shown by climate-based daylight and thermal simulations. Here the reflectivity of ground and facades had a great impact which should be considered in future design processes in dense areas. There is a delicate balance between climate, materials, and urban patterns and how daylight is distributed in the complex geometry of urban canyons was before their research considered less important.

Other studies regarding urban canyons have underlined the effect of densification in Nordic countries where there are plenty of cloudy days and scarcity of natural light affecting daylight conditions. Lami (2018), who developed a methodology based on two parts; 1) measurements of illuminances, material's reflectance, false-color photographs, etc. and 2) a qualitative survey (questionnaire-based interviews), tried to establish a relationship to define how optimal this urban pattern could be for visual comfort. Respondents based their evaluation on subjective experiences and on the sky conditions. However, some proprieties of the materials seem in the urban canyon (color, contrast, reflection and specularity) acquired more importance in the conclusion. These characteristics played a big role in the people's assessment despite the site's geometry. Many physical and cultural factors are involved in this evaluation and the thesis concluded aiming to other researchers to continue studying people's subjective assessment of outdoor spaces and daylight (Lami, 2018).

Li and Tian also studies some physical characteristic of buildings and urban layout that have influence in the solar potential for individual buildings, both passive solar heating and active solar potential for energy production. Building shape, density, roof slope and building envelope were some of the parameters studied and they analyzed those parameters along several sunlight and solar metrics. The goal was to suggest better ways for urban planning for the early-stage design in cities (Li & Tian, 2020).

Saratsis, Dogan and Reinhart also studied the effect of urban densification and daylight access. They offered a method to quantify the performance of building proposals before construction in opposition to the current zoning guidelines and section-based geometries evaluations that municipalities usually follow. The authors encouraged responsible people and developers use climate-based daylight metrics to make or break the daylighting potential of a whole neighborhood. The use of these simulations enables more accurate and detailed zoning rules. Finally, the authors evaluated the daylighting performance of several typologies in New York City to demonstrate that some massing approaches outperform other conventional massing strategies. The authors showed with a real case (a city block in New York) that innovative massing strategies could improve daylight performance for the block itself as well as for the surrounding buildings (Saratsis et al., 2017).

Other investigations have looked to the current regulation and daylight or solar access. In 2019, de Luca and Dogan made a review of some solar access requirements in urban planning for different countries and/or cities. They classified the different ordinances regarding if they request a new building not to obstruct the existing dwellings around it for a specific interval of hours, not to obstruct them for a certain number of hours or not to go further than a fraction of the neighbors' current solar access during a new building's design stage. De Luca and Dogan developed a computational method for creating solar envelopes (SEs) for new buildings which included the existing context and let architects and urban planners to choose quantity and quality of sunlight hours. Their method was suitable for the three types of ordinances and overcome the limitations of previous methods using SEs. The research aimed to help municipalities and professionals to determinate the right sizes of buildings for environmental purposes and the authors thought in creating a set of software tools for popular programs, like *Rhinoceros*. Currently there is a Beta version of these tools for free (De Luca & Dogan, 2019).

There are not only daylight and solar studies for outdoor spaces. There are also many investigations about climate and behavior in urban spaces.

Eliasson et al (2007), analyzed four urban public spaces in Gothenburg, Sweden, to find arguments to use climate-sensitive design in urban planning and boost people attendance to the public space. The research was multidisciplinary and involved different professional carrying out measurements of meteorological data, observation and interviews at each site. They found that parameters as air temperature, cloud cover and wind speed influence the perceptions of those spaces and user's attendance (Eliasson et al., 2007).

Another research that focused on outdoor spaces and user's behavior and perceptions of comfort was a post-occupancy evaluation carried out by Göçer et al (2018) in Istanbul, Turkey. They conducted annual measurements and analyzed the connection between people's behavior and physical attributes of a courtyard. They carried out a questionnaire-based survey, used surveillance cameras to capture a behavioral map and elaborate spatial and spatial-temporal maps to understand better user's experience and preferences. The method was intended to be applied in managing buildings for the construction and design sector to identify whether a space has been successfully planned and user practices (Göçer et al., 2018).

A pilot study by Yanga, et al. (2016) explored the connection between microclimate and human behavior in different parks in Umeå, (Sweden). The study was carried out in summer and measured parameters as dry bulb temperature, relative humidity, wind speed and solar radiation. The authors conducted observations and structure interviews based on a designed questionnaire. They compared the technical measurements with the subjective responses and found that the local people preferred higher solar irradiation when the thermal sensation is still slightly warm for the Thermal Sensation Vote (TSV). Other findings were the different expectation from local to non-local people in solar expectations (the Swedish indicated higher expectances than the non-locals) and the better adaptation to the climate by the locals. Finally, the study showed that wind sheltering and solar irradiation together can improve thermal comfort, thus, the result could be used for designing outdoors spaces under a similar climate (Yang et al., 2016).

Lam et al. (2020) analyzed the cross-modal effects of thermal and visual conditions for human comfort perception of exterior spaces in China. They interviewed hundreds of people in 2018 using the Universal Thermal Climate Index (UTCI) and sky conditions to find potential interactions between those factors. They found a high correlation between sun sensation and sun preference with heat stress conditions and thermal comfort votes. Under intense heat stress the thermal sensation was more uniform regardless the sunlight preferences, but it was found a clear cross-modal effect on sun sensation and sunlight preference under different sky conditions. The authors dared to suggest outdoor thermal discomfort could be lessened by increasing visual comfort and the other way around. They encouraged urban designers to consider both visual and thermal conditions together for improving the pedestrian's experience and livability of outdoor spaces (C. K. C. Lam et al., 2020).

2 Methodology

This study tried to respond to the research questions through qualitative methods mainly, but with a supplement of quantitative methods. This complementary method, featured as technical measurements, was expected to help triangulating the findings or give additional information. Some generic principles are the use of direct observations for studying people's behavior in public space, as squares, streets or alleys, while spaces as courtyards or indoor spaces can be study with a more suitable approach as interviews or questionnaires. However, in order to know what people think or what they believe, it is recommended to use interviews, questionnaires or attitude scales. Nevertheless, these methods are often used together, so the reliability and validity of research findings increase (Robson, 2011a).

Before the execution of both parts, a literature review was performed to explore previous research related to public space and as inspiration. Moreover, some simulations were run for different Daylight metrics in order to have a better understanding of the places before the surveys. The idea also was to explore the different sites and check whether they were comparable under the same methodology.

The assessment of people's behavior and evaluation of the solar access was divided in two different surveys. The first part was a qualitative survey, a questionnaire-based interview. As supplementary method, some direct observations and quantitative measurements were included. Furthermore, some pictures were taken with a regular photograph camera and with a drone.

After the results and interpretation of the first survey, a second methodology to complete the research was included. For the second survey a qualitative survey was carried out, based on an intensive observation over two different squares for different sky and weather conditions.

2.1 Place selection

The selected place for both surveys was *Katedralstorget* in Lund (Cathedral's square) shown in Figure 1. This emplacement belongs to the heart of the old city, in the proximity of the main administration buildings of Lund University and other important squares. It was chosen in first place for being a popular public space for people and easily accessible for the survey.

The square is a rectangle of approximately 65 m length and 35 m width, oriented southeast to northwest. The northern side is closed by the cathedral and to the south the two-story buildings of the *Domkyrkoforum*. The square is flanked to the east by *Kungsgatan* and a red brick house containing a library and to the west by the street of *Kyrkogatan*. The materiality of the square is defined by a hard stone tile patterns for most of the paved surface and a variety of the patterns in the areas around the main buildings. There are some wooden benches with four small ornamental trees in the opposite side of the square (Figure 2) and some wooden benches at the foot of the granite façade of the cathedral (Figure 4). There are wooden benches beside the library too. Most of the facades here lack public use on the ground floor or entrances, so there are any destinations in the square except for the *forum* entrance.

Figure 1: Katedralstorget. Picture from Google Maps.

After the second week of spring, the municipality left some steel-wooden low seating cubes in the square as it is seen in Figure 3. Some of them were placed beside the benches on the southern side, a few were left in the middle of the square and the rest were left beside the cathedral.

Figure 2: Wooden benches (south) and Figure 3: Seating cubes left by the municipality. Pictures by Alejandro Manso.

Figure 4: Façade benches (north side of square). Picture by Alejandro Manso.

Similar squares were chosen as secondary options as an opportunity to increase the number of studied sites and as a plan B in case of the original site was not available. Thus, *Mäster Palms Torget* in Helsingborg were included as possible candidate for site exploration. Later, *Clemenstorget*, although larger than the others, was added to the list of sites.

Mäster Palms Torget (Figure 5) is a trapezoidal square, almost rectangular. The length is around 60 m and the deep 30 m on the short side and 40 in the opposite. The rectangle, oriented east to west is open to *Södergatan* to the east and *Karl Krooks Gata* to the west. In this square the facades are more permeable, with a secondary school, some restaurants and shops in most of the perimeter. However, the southwestern corner consists in an opaque wall with no use. Some trees on the north protect one of the long sides from solar irradiation. Some circular wooden benches with a flowerpot in the middle are at the entrance from the adjacent *Södergatan*, and a couple of long benches more on the other side, with a short concrete wall as protection for the traffic noise from *Karl Krooks Gata*. There is a terrace in the downside that belongs to a coffee shop, a second one on the upper side as exterior serving area for a restaurant and a last one in the opposite corner for another pub restaurant. The building on the north side is six story buildings, meanwhile the southern side is composed by a shopping mall of eight levels.

Figure 5: Picture of Mäster Palms Torget at morning in latest April. The shadow covered most of the area. Picture by Alejandro Manso.

The ground is covered by a stone tile pavement, except for an elliptical area to the west with a smooth plastic grass finishing. There is a parking for bikes in the northeastern corner. There are some steel folding chairs that the municipality placed in the elliptical area and some hard plastic volumes as table/chair outdoor furniture as well. After the second week of spring the municipality increased the number of folding chairs in this area.

Some complications found in the first square made it necessary to move the survey to other space (Figure 6). This new site was *Clemenstorget*, in Lund and close to *Katedralstorget*. In the following picture, the crane that disturbed the survey was cutting the circulation for pedestrians and avoiding them sitting on the benches and, presumably, altering their normal behavior.

Figure 6: Picture of Katedralstorget the 18th of March. A crane was altering the normal functionality of the square and the benches were not available. Picture by Alejandro Manso.

Clemenstorget (Figure 7) is slightly larger than the previous one and with a more open character, being its shape closed to a square of 110 m side. The space is situated in front of the train station, surround by two to three story buildings. It has a combination of stone tiles on the floor and some permeable areas with sand. There is a grid of canopy trees separated around 6 m from each other. In summer, the canopies form a shade which covers a large area of the square. On the ground, many steel chairs in different groups and orientations stand distributed along the square (Figure 8 and Figure 9). There are also other alternatives for sitting, like wooden benches and small circular play pavilions with benches inside. Other features found here are some steel sculptures called "*Spetstak*" with a function of shading devices.

There is a stopping place for the tram, whose tracks reaches the center of the square. Many of the city buses have their stop in the adjacent street between *Clemenstorget* and the train station. Therefor it is a well transited area by the people.

The facades on the ground floor contain public uses as a grocery, a restaurant with winter and summer terraces and some shops (east and south).

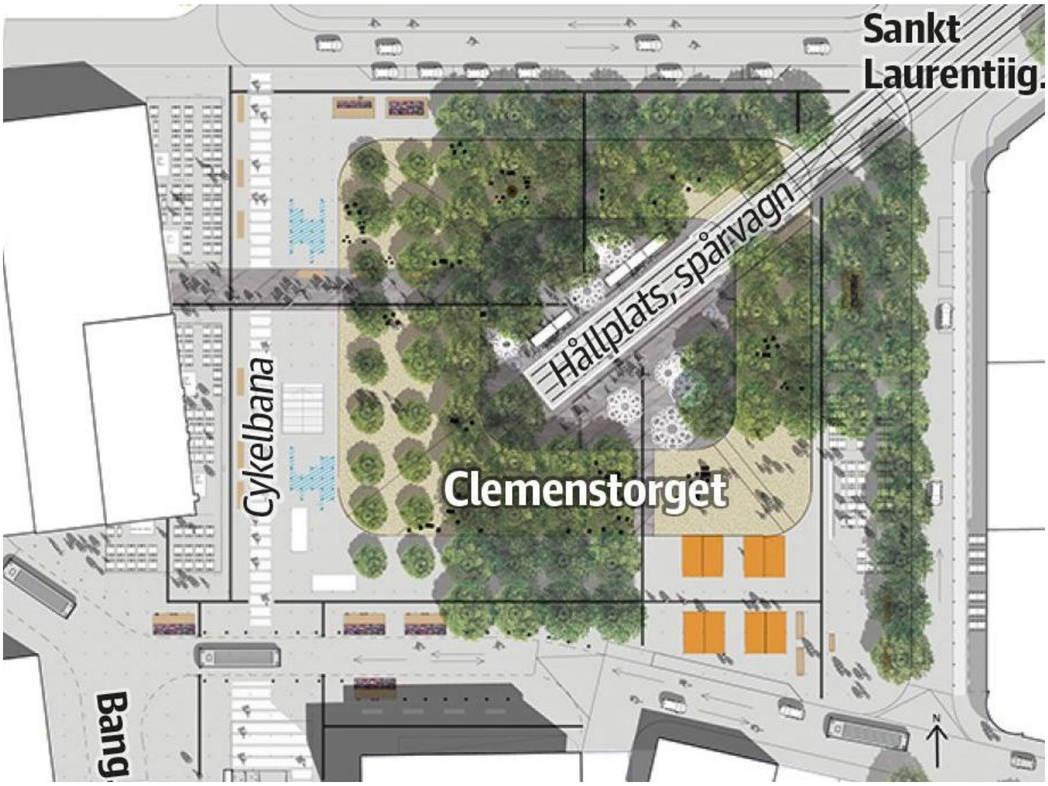


Figure 7: Clemenstorget, design and image by ©White Arkitekter. (Martelius, 2017).

Figure 8: A man smoking peacefully in one of the steel chairs. Figure 9: A young man waiting for the public transport. Pictures by Alejandro Manso.

2.2 Model and simulations setup

The chosen locations were built in *Rhinoceros*. The model was simplified to a basic massing consisting in pure volumes. These volumes represented the buildings without balconies, shading devices, signals, decoration, or other details. Some minimal height changes existed on the ground; however, this was built as an almost flat plane. The materials were also simplified, using only one for all the buildings' volumes, representing a mix of solid materials, reflective metals and glazing. Facades and roofs were considered as the same, meanwhile neither windows nor doors were drawn. Other single materials were given to the ground's surface, to the trees' branches and to the canopies.

The urban furniture and other features were ignored for the simulations, although they were considered in the interpretation of the survey's results afterwards. The trees were divided into the canopy and the trunk with a simplified set of branches. Winter simulations ignored the canopies.

For the simulations and sunlight hours calculation, the plug-in *Ladybug* for *Grasshopper* in *Rhino* was used. The reflectance of the building materials was set at 30 % as an average of different exterior materials both for facades and roofs. For the ground, a 20 % reflectance was assigned after a parametric study where no large differences were found for slightly higher reflectance values. The adopted reflectance represents all the paving as asphalt, dark and clear tiles… and grass in the space and surroundings. The trees had an assigned reflectance of 20 % for branches and trunks, and 40 % for canopies with a level transparency of 60 % for summer conditions and 100 % for winter. The daylight plane was set in 1.65 m above the ground, at eye's level. For each square it was used the last version of the weather file of its city found in Climate.OneBuilding.Org (Lawrie & Crawley, n.d.).

The raytraced parameters for *Ladybug* were *(-aa .15 -ab 2 -ad 512 -ar 256 -as 128 -dr 2 -ds .2 -lr 6 -lw .004 -dj 0 -lr 6 -sj 1 -st 0.15)* and a quality of 0, the lowest. The size of the grid was 1 m for simulations in general and 0.5 m for the sunlight hours' analysis.

After the literature review, the following metrics were chosen for being studied:

Direct sunlight hours
This value indicated the number of hours with direct sunlight for the space. Different time ranges were studied. First, summer and winter, for a general comprehension of the space. Afterwards, the 21st of March was calculated hour by hour and for the length of 12 h, from 7.00 am to 7.00 pm.

Daylight Autonomy (DA)
This metric indicates the percentage of the occupied hours of a space along the year when a minimum illuminance at a point or a grid of them is met only by daylight. This metric was studied for the period of winter and summer separately with a threshold of 2 500 lux.
The time range was 8.00 am to 17.00 pm, where most of diary activity occurs during working days.

Continuous Daylight Autonomy (cDA)

This metric is a modification of the DA where partial credit is given to the daylight when illumination level is lower than the threshold.
Using a threshold of 10 000 lux and the same time range as the DA, this metric has been linked to user perception of an outdoor space in previous research, meanwhile DA addressed the expected illuminance level for plant growth (De Regt & Deak, 2019b).

Annual Klux-h
This metric represents how much light this space receives by multiplying the illuminance levels by time. The annual Klux-h of the squares was compared with the city baseline to find the percentage of light received over the potential Klux for this latitude. The simulation ignored the totally urban context and just used a plane ground for the city baseline.

Sky exposure
It represents the proportion or percentage of sky seen from every point of a test surface. It gives the same weight for each portion of the sky.

Average illuminance values.
The average illuminance of the space was calculated for the periods of October to March (winter) and April to September (summer) for separated intervals of time (Morning, Noon and Evening). The schedule started at 8.00 am until 17.00 pm in sets of 3 h. As in the Annual Klux-h, the averages were calculated afterwards for the city baseline in order to compare and find the percentage.

2.3 First survey

The first methodology followed was a qualitative survey. This consisted in a questionnaire-based interview and additionally, field point-in-time technical measurements and field point-in-time direct observations. The interview was designed as a face-to-face short talk with users of the square. Also, the survey was structured and designed according to a protocol.

The initial selected time to carry out the first survey was the 21st of March. This is a marked date in the year because it is the equinox, and this could work as reference for future comparisons with other dates. However, the survey was divided into different partial times to cover different sky conditions and because the limitations of the academic time and unfortunately, other factors as the unpredictable weather. A clear sky and an overcast sky were preferable to the study, so the choice of the days came according to the weather conditions and with the availability of time. The goal was to have as many people as possible in the available time around the equinox. It was fixed an interval of one week down and one week up from the 21st. The time span selected for the survey was between 9.00 a.m. and 12.00 p.m., where it was supposed to find more human activity for a working day.

The method followed the shown diagram below these lines, in Figure 10. Notice that “day 1” and “day 2” did not correspond with complete days, but with two useful days made by half of others within the prerequisite of the mentioned time span.

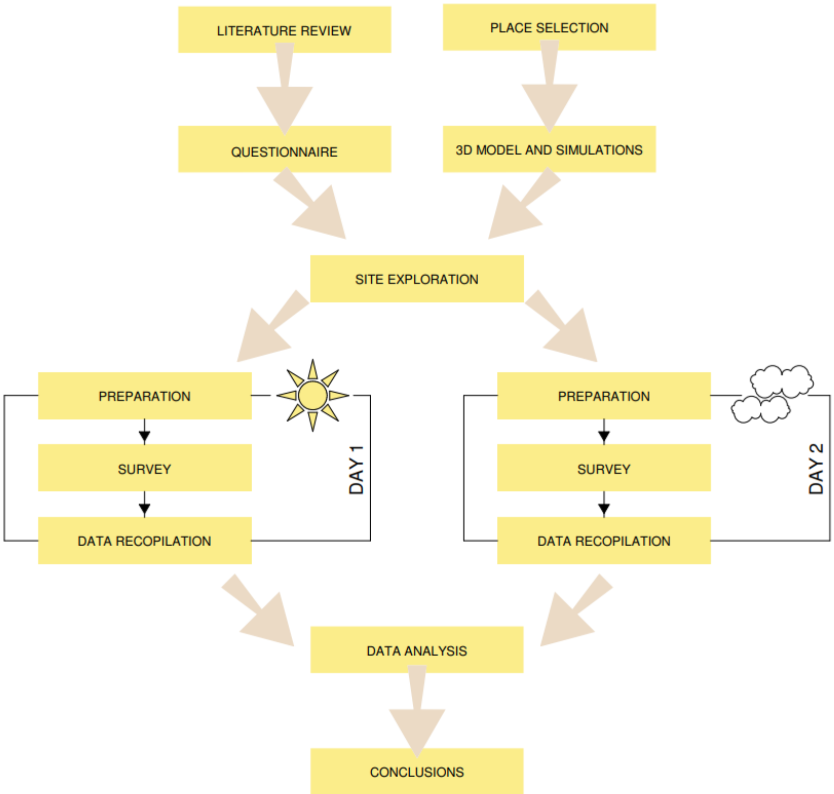


Figure 10 Original diagram for the method/approach.

2.3.1 Questionnaire's setup

Questionnaire-based surveys have some disadvantages. The data could be affected by the respondent's motivation or personality. The interviewer may bias or influence the responses, unwittingly. Other interactions between interviewer and respondent could affect, or between a group of respondents. On the other hand, some advantages could be the possibility of clarifying questions during the interview, for example. The interviewer might encourage participation as well. The mainly advantage is the straightforward approach to the study that provides this method to seek values, beliefs and motives of the people (Robson, 2011b, p. 9).

It is common to always follow sequence in the questionnaire (Robson, 2011c, p. 284). First, there is an introduction where the interviewer introduces himself, ask for permission, explains the purpose of the interview, assures confidentiality and if needed, encourages people to participate. Some easy questions to warm up follows before the main body of the interview. To diffuse tension and give opportunity for additional comments, some time was given to the respondent. In this survey, the possibility of adding comments was mentioned before the main body of the questionnaire and at the end of this. Finally, a closure to thank for the time and participation.

The questionnaire was written both in English and Swedish. The warm-up part contained a group of generic questions which referred to individual factors. These first questions (Q1 to Q4) were created for collecting basic information as the age, gender, origin of the person and reasons for visiting the site. People were asked where they came from in order to separate locals of tourist due to the goal of this research was knowing how Swedish people evaluates solar access, which could differ from other cultures. For the last one (Q4), the option for an open answer was given.

A 4-point Likert scale was used for the main questions (Q5 to Q12 in the questionnaire), although a *No answer* option was given as well. The interviewer left the option for adding open-answer comments for each question to collect more qualitative information.
The main body was divided into two blocks for solar access' questions and daylight's, respectively. At the same time, the blocks contained two questions for each of the following factors: visual comfort and pleasantness.

Visual comfort is subjective, and it is related to the quantity and quality of light within any given space. *Pleasantness* could refer to psychological pleasantness or aesthetical pleasantness. A daylit space can be comfortable for human being in terms of visual performance, but not pleasant and vice versa. These factors were used later to correlate the measured horizontal and vertical illuminance beside the bystander. Table 1 and Table 2 show the final questions. Q5, Q8, Q9 and Q11 corresponded to visual comfort, meanwhile Q6, Q7, Q10 and Q12 corresponded to pleasantness. There was not expectation for perfect correlation because other factors could influence the perception of the people answering the interview.

Some questions were similar (the English version) for daylight and solar access to try to separate both concepts in the results, like Q6 and Q10.

Table 1: Main questions for the questionnaire-based interview.

FACTOR	SOLAR ACCESS Question	
VISUALCOMFORT	Sunlight is bright enough for the activity I am doing now. **Det direkta solljuset är starkt nog för aktiviteten jag ägnar mig åt nu.**	Q5
PLEASANTNESS	The direct light from sun is pleasant right now. **Det direkta solljuset är bekvämt just nu.**	Q6
PLEASANTNESS	The current level of sunlight encourages me to spend more time at this location. **Den nuvarande solljusnivån får mig att vilja spendera mer tid på den här platsen.**	Q7
VISUAL COMFORT	It is tolerable to have direct sun in my eyes/ my face right now. **Det känns acceptabelt att få direkt sol i mina ögon/ mitt ansikte just nu.**	Q8

Table 2: Main questions for the questionnaire-based interview.

FACTOR	DAYLIGHT Question	
VISUAL COMFORT	Daylight here seems appropriate for what I am doing right now. **Dagsljuset här verkar passande för vad jag gör just nu.**	Q9
PLEASANTNESS	Daylight in this space looks pleasant right now. **Dagsljuset på den här platsen ser trevligt ut just nu**.	Q10
VISUAL COMFORT	The level of daylight seems bright enough in this place now. **Dagsljusnivån verkar för tillräckligt på den här platsen just nu.**	Q11
PLEASANTNESS	I am satisfied with the daylight in this place right now. **Jag är nöjd med dagsljuset på den här platsen just nu.**	Q12

The complete questionnaire is attached in the Appendix A.

The field observations were carried out before approaching a potential respondent. The interviewer played an invisible role until he revealed himself to the potential respondent. This allowed to do not affect people's behavior until the interview was started. In these observations the interviewer took notes if it was detected some kind of distraction or influence on the respondent.

For this purpose, an observer´s sheet was attached to the questionnaire for each person. This information included as inputs: the date and time when the interview was conducted, some space for notetaking into the paper the illuminations from the measurements, the position in the space of the person marked on a small map, the social and physical engagement, as well as other activities like eating, reading, smoking…, the orientation or main direction of the eyes and complementary information in form of notes. The Appendix B shows the observer's sheet for the first survey.

2.3.2 Measurement' setup

Parallel to the questionnaire-based interview, some measurements were carried out to complete the survey. First, two small portable devices (*Figure 11* and *Figure 12*) were used for measuring temperature and illuminance in two different spots of the studied square. These devices were HOBO Pendant sensors which can be connected by Bluetooth to the smartphone with the assistance of an app where it could be read the results or downloaded. The sensors measured the temperature and the horizontal illuminance each second and calculate the average and standard deviation for each minute. For a clear sky, the first sensor was placed in a shaded area and the second in a sunny area, therefor, the difference in illumination could be compared later. For an overcast day there was no distinction where to place the sensors, although it was a good practice to search for places where people could not affect the measurement.

Figure 11: (Sensor 1) and Figure 12: (Sensor 2). Picture of the sensors ready for collecting data during the first site exploration. Pictures by Alejandro Manso.

Large fluctuations in the measurements of the HOBO sensors were recorded the first day, both in temperature and illumination. The initial and final variations occur when the devices were taken from inside the bag or pocket of the interviewer and put in place. Removing or obviating these fluctuations, more small fluctuations on the graph was due to the unstable condition that first day in the sky. The intermittent presence of clouds decreased the irradiation reaching the square and potentially, the interruptions of the ongoing human activities affected the graph too.

A third tool was included in the equipment for the survey. A Lux meter which was carried by the interviewer to measure horizontal and vertical illuminance beside the people who participated on the interviews. The horizontal and vertical illuminations were measured at the eyes´ height. Thus, when people were standing or walking this height was approximately 1.6 m, and when they were sitting, around 1.2 m. The number is an approximation because there was not a way to measure an exact height over the ground and every person has different eyes´ height and posture. A couple of bubble levels were used to control the level and plumb of the tool, due to the big fluctuations noticed during the measurement when the tool was slightly tilted.

Moreover, pictures were taken with a camera and by a drone. This second was used to capture bird-eye pictures of the space during the survey and as a test for further investigations. The intention was to create a heatmap of the site and people s behavior. The drone took snapshots at intervals of 20 s. The flying was performed in collaboration with a second person to be able to interview the people meanwhile the drone captured the images.

2.3.3 Protocol and procedure

A protocol was written to structure the survey and follow the same steps along all the days. It was also an approach to organize the procedure and keep under control the many tools needed for this method. The sunlight hours analysis was used to know where to place the HOBO sensors before to arrive to the site.

The procedure for the survey after arrival to a square was as follows:

1. Location of positions where to place the sensors.
2. Starting a preliminary observation to keep control of the activity and the people.
3. Survey.
    a. Find a position of the space where to fly the drone and start the survey. Wait for a target (person). Every person in the space should be consider as a potential respondent and any kind of distinction is made. The choice is random.
    b. Find a person or small group of people.
    c. Observation data is written down using one sheet for each individual person, writing down an identification number, and marking the position of the target on the map. Other clarifications could be added to the paper if needed. The identification number must be the same for the observation's sheet and the questionnaire.
    d. After each person or group has been observed and the basic information is written on the observer's sheet, it is time for approaching the subjects.
    e. The interviewer will approach the people first and ask for a short interview.
        i. The interviewer will introduce himself as member of Lund University, point out that the survey is anonymous and be polite whatever the situation is.
        ii. If the person refuses, the interview is cancelled and, in the sheet, it will stand ''DID NOT PARTICIPATE" or similar. The observation and the cancelled interview will remain with the same number as it was written in the step c.
        iii. If the person agrees, the interviewer will read the questionnaire and fill the information.
        iv. If the interviewer sees a reason to consider the answers wrong or misleading, should consider removing it afterwards. For instance, people who indicate that they are comfortable with direct sun in their eyes meanwhile wearing sunglasses.
    f. The interviewer, with the Lux meter in his hand, will measure the illuminance during the interview. It is important to consider:
        i. The measurement will be carried out trying not to interrupt or distract the interview in progress.
        ii. The measurement will be carried out trying to keep the tool at 1.60 m of height approximately above the ground, in a position between the person who is interviewed and the sun position in case of being in a sunlit area.

iii. In case of that the observed person is sitting or lying, the tool will be placed at his/her eye's height approximately.

g. When both tasks are finished, the interviewer will search for a new person.

h. When the drone has run out of battery will be landed, but the survey will continue.

4. The survey will end when 20 to 30 people have been interviewed or at 16.00 pm.
5. If survey is repeated another day, it will follow the same steps as in 1 to 4.
6. The data for the different days will be put together in *Excel*, where it will be analyzed.
7. The results will be plotted:
    a. The distribution of people who participated in the surveys according to the age and gender.
    b. If there are tourist, their results could be separated for later comparison.
    c. The average result of the factors of pleasantness and visual comfort will be calculated to correlate the measured illuminance.
    d. The correlations will be plotted separately for each factor and for each sky condition.

2.4 Second survey

As the second part of the assessment, an observation-based survey was carried out. A structured observation assessment was conducted as the main methodology for the some of the squares previously explored. *Katedralstorget* in Lund and *Mäster Palms Torget* in Helsingborg were chosen for this survey to continue with the spaces that originally were though for the entire study and already explore in the first part. Clemenstorget was discarded because was too large for observations with this second methodology. This observation was a mixed strategy, combining part of qualitative (verbal and non-numerical findings) and quantitative (information presented as accurate measurements and numbers) observations (Robson, 2011d, p. 241)

Time, illumination, number of people and other quantitative aspects were measured or accounted. The observation schedule becomes the instrument of the study, as opposed to the observer as instrument in participant observations (Robson, 2011e, p. 232).

Because it was in public spaces, the data recording was feasible and ethical the when the studied subjects (people) were not conscious or had given any consent. Asking for permission had interrupted the survey and the value of the data. One advantage of the observations is that these occur in a natural way, in a natural environment of the daily life. Thus, the methodology should gather reliable inputs (Adler & Adler, 1998).

The observations took place during a period of several days with the intention of having different sky conditions for both squares to compare. As it is shown in Figure 13 a workflow was followed for the survey. The time span was a maximum of 3 h between 9.00 a.m. and 16 a.m. Weekdays were chosen for the observations. It is remarkable to know that days before a weekend or other festivities the regular pulse of the city could be altered (Gehl & Svarre, 2013). So, it is better avoiding days like these.

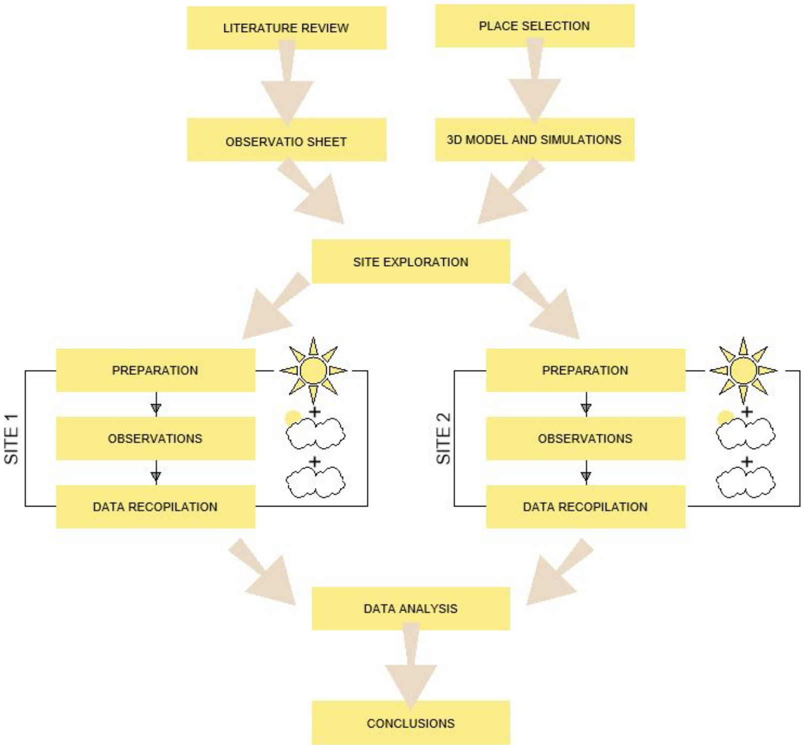


Figure 13: Diagram for the method followed for the second survey.

The observer was a marginal participant, adopting a passive role in the square as a casual random user of the public space. By this it became difficult or impossible for people notice the presence of the researcher and thus, nobody changed their natural behavior. To be more indistinguishable, careful attention to dress code and behavior should be kept in mind to avoid people's perception of an observer.

The Danish architect Jan Gehl, in his broad experience studying people in urban contexts, classified the outdoor human activities into three categories: necessary activities, optional and social activities (Gehl, 2010). The first type gathers all activities that people do regardless of the quality of the physical environment, like walking for going from A to B, working, shopping, parking the bike, etc. Optional activities are linked to what a given space can offer to people or how make them feel or behave. These actions show a desire from a person to do something, an often some preferences in time and space. They are more common under optimal weather conditions and less common under poor weather conditions, among other factors as functionality, etc. Examples are strolling, reading a book, jogging, eating lunch, etc. Finally, the social activities are when some social interaction happens. They are spontaneous many times and occur when the first and second categories are taking place. These activities are casual conversations or meeting, children's play, just watching other people, etc. attractive and meaningful outdoor spaces create a frame for all of these three kinds of activities combined, making them feed each other. The observation was designed to record these three kinds of activities for a later comparison with the solar access.

2.4.1 Observation setup

The squares were divided into two zones of observance after the sunlight hours simulation result, having the area with the most direct sunlight in one zone and the area with the least hours in a second zone. The reason behind this was to limit the space in smaller areas where visual contact over the people was possible. For each zone and interval, a different observation sheet was used. The sheet was as a double side page where all the information was logged.

The observation data was divided into three parts; thus, the sheet reflected this division. First, a table for general conditions, second, a map for marking the position of the samples and afterwards, be able to plot a behavioral map, and finally, a sampling table for the main information. In this main information it was included a subjective interpretation for wind speed (no wind, windy and very windy) as a way to include this factor in the observations. Sky conditions also was noted.

The sampling table contained four categories of data: basic information, physical engagement, social engagement and complementary activities. Table 3 summarizes all the different categories, divisions and codes inside them. The categories had space for notes under the different items, where qualitative information is written down. Necessary activities were out of the observation to simplify this study. All the people passing by or coming to a final destination in the buildings around the square were omitted. People parking a bike were as well omitted. People would do them regardless the solar access in many cases. People doing nonstationary sports like jogging or running, or working was omitted as well

The category for physical engagement or primary activity, referred to the position of the observed person. Most of them are stationary, like sitting, lying... It was included an option for *Hanging out* because this activity implies sometimes more than one position in a short interval of time. This was considered especially for teenagers and young people.

The social engagement referred to the social interactions of the people. It was noted as passive if a person was in silence or distracted. On the other hand, it was noted as active if there was some verbal communication or physical contact. In this category it was mentioned if the observed people were alone or part of a group. A couple of people sitting together was accounted as two samples, with the same Group ID. If they were together from the beginning of the interval, they got the code “Tg”. If a third person arrived and joined the group, this got a different sample ID, but same Group ID. However, the code “*M*” for meeting would be recorded.

Complementary activities are written down for leisure activities or other human behaviors like “Adapt the environment”. This definition refers to when a person or group move the furniture or use this with another purpose than the original given to this object. For example, some people in Katedralstorget used the seating cubes as tables.

Table 3: Main categories and codes for the sampling table.

BASIC	ID	*1, 2, 3, 4, 5, 6…*
	Age	*Baby (B) / Child (C) / Teenager (T) / Young (Y) / Adult (A) / Senior (S)*
	Gender	*Male (M) / female (F)*
	Solar access	*Sun (SU) / Shade (SH) / Overcast (OV) / Partially (PA)*
	IN	*(hh.mm)*
	OUT	*(hh.mm)*
PHYSICAL ENGAGEMENT	Standing	*“X” if Yes, blank if No*
	Sitting	*“X” if Yes, blank if No*
	Walking around	*“X” if Yes, blank if No*
	Lying	*“X” if Yes, blank if No*
	Hanging out	*“X” if Yes, blank if No*
	Other	*“X” if Yes, blank if No*
SOCIAL ENGAGEMENT	Passive	*“X” if Yes, blank if No*
	Active. Talking	*“X” if Yes, blank if No*
	Active. Physical contact	*“X” if Yes, blank if No*
	Group ID	*1, 2, 3, 4, 5, 6…*
	Meet/Together	*Meet (M) / Come together (TG)*
COMPLEMENTARY ACTIVITY	Eating	*“X” if Yes, blank if No*
	Snack/Beverage	*“X” if Yes, blank if No*
	Smoking	*“X” if Yes, blank if No*
	Reading	*“X” if Yes, blank if No*
	Music	*“X” if Yes, blank if No*
	Telephone	*“X” if Yes, blank if No*
	Sun bath	*“X” if Yes, blank if No*
	Engage with feature	*“X” if Yes, blank if No*
	Adapt the environment	*“X” if Yes, blank if No*
	Sun protection	*“X” if Yes, blank if No*
	Other	*“X” if Yes, blank if No*

In this survey, as in the first one, a protocol was written to structure the observations and follow the same steps along all the days. It was important to be constant during the procedure and write down the data in the same way for the later analysis. The protocol is attached in Appendix D.

It is necessary to highlight the requirement of getting familiar with the observation sheet, its structure and codes or categories there, to be efficient when it is time to carry out the observations. For example, the gender for females was typed as '*F*' and for males, '*M*'. More complex was the code for the solar access, being '*Su*' for a sunny place, '*Sh'* for a shaded place or "*Pa*" for a situation in between when people have partially the body in the sun and partially in the shadow, etc. The observation's sheet was developed after a previous observation study by Henning (2021). It can be seen in the Appendix C.

The age of the people is estimated and not a quantitative accurate value, but a subjective interpretation of the observer. It is difficult to know where bias or interpretation of the person who is carrying out the survey may affect the results. Although in a qualitative research this is a common phenomenon: the point of view of the observer might interpretate information in different ways (Robson, 2011e, p. 232).

The observation should reach a theoretical saturation when the events are repeated and no new information is obtained (Adler & Adler, 1998). In this methodology with only a weekday for each square is enough if the sky and weather conditions are similar for all the samples.

3 Results

3.1 Site explorations

The site exploration for the three squares included in this study are shown next. Not all the metrics were simulated for all the squares.

3.1.1 Katedralstorget (Lund)

The shadow studied showed the areas most exposed to direct sunlight and those which are most excluded from direct sunlight. The middle area of the square and northern side beside the cathedral's façade are the spots with more hours of sun. In Figure 14 an hourly analysis is shown.

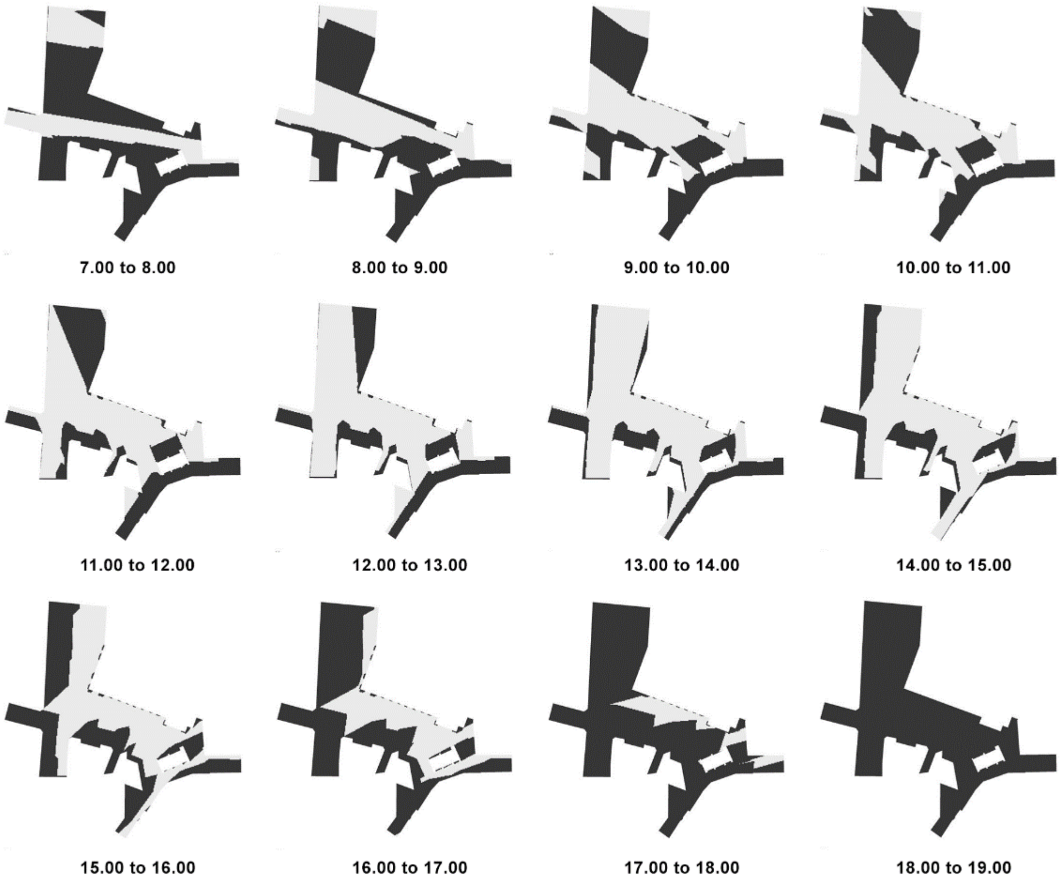
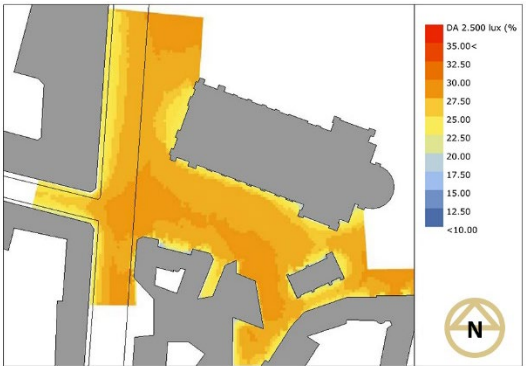


Figure 14: Hourly analysis of sunlight hours for the spring equinox.

The simulations for the cDA 10 000 lux and DA 2 500 lux showed a large uniformity in terms of daylighting for both metrics. Figure 15 and Figure 16 show the results for these metrics under winter conditions. Slightly higher levels were found in open areas with larger exposure to the sky. Lower levels for both metrics were found in the same places where the square receives less hour of direct sunlight.



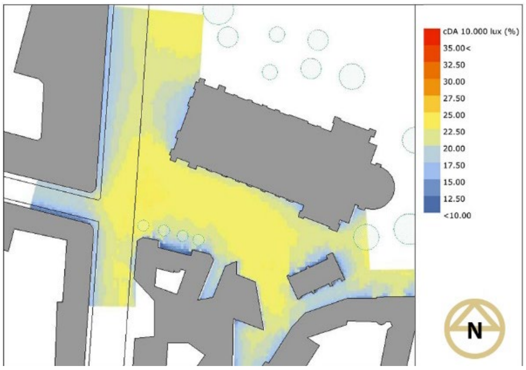
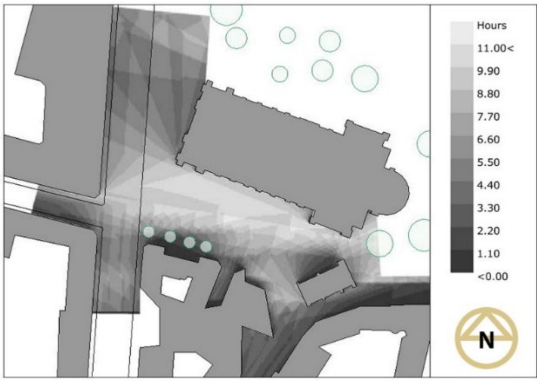


Figure 15: DA 2 500 lux and Figure 16: cDA 10 000 lux, both for winter conditions.

Under winter conditions the upper side of the square receives more hours of sun (Figure 17). In general, at the level of the pedestrians, the portions of sky they were exposed to was around 70% in general and slightly lower than 50% beside facades (Figure 18).



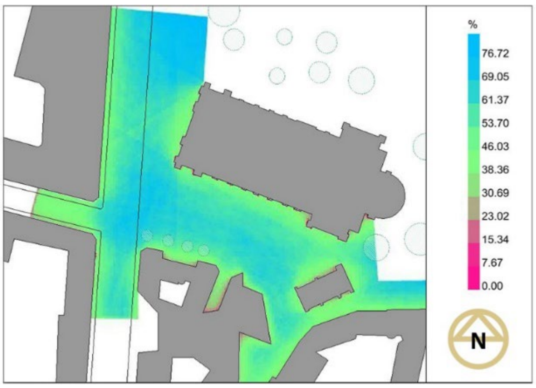


Figure 17: Direct sunlight hours analysis for winter conditions. Figure 18: Sky exposure simulation for Katedralstorget.

3.1.2 Clemenstorget (Lund)

The cDA resulted around 30 % of most of the square's surface. The DA 2 500 was extremely uniform as well, around 40 %. Both are shown in Figure 19 and Figure 20. The round circles represent the trees' positions.

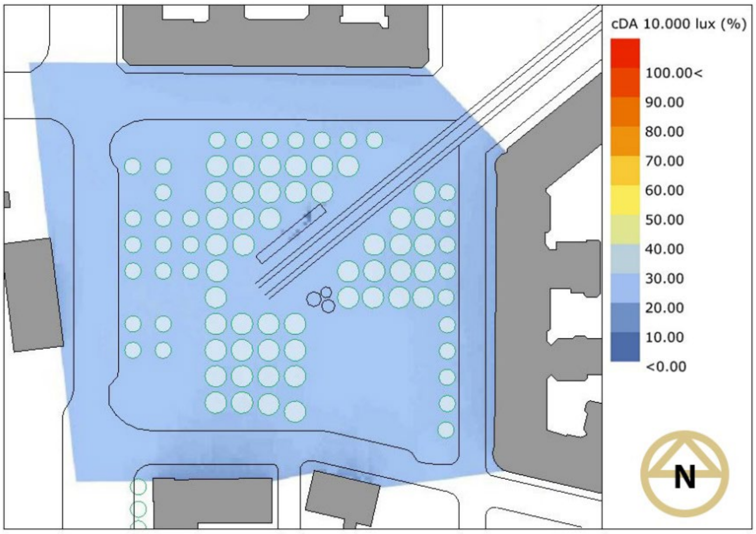


Figure 19: cDA 10 000 lux for Clemenstorget under winter season.

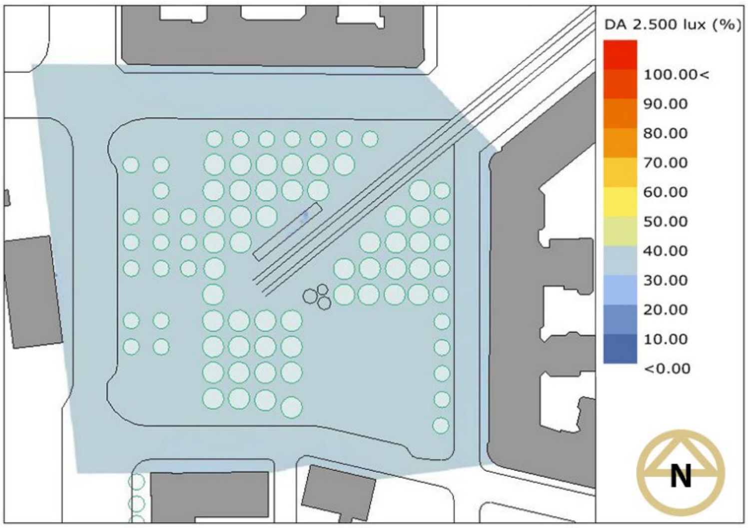


Figure 20: DA 2 500 lux for Clemenstorget under winter season.

The sunlight hours analysis showed areas with a low number of hours with direct sunlight, the southern and eastern sides. The longest sunlit area corresponded to the northwestern corner. See Figure 21.

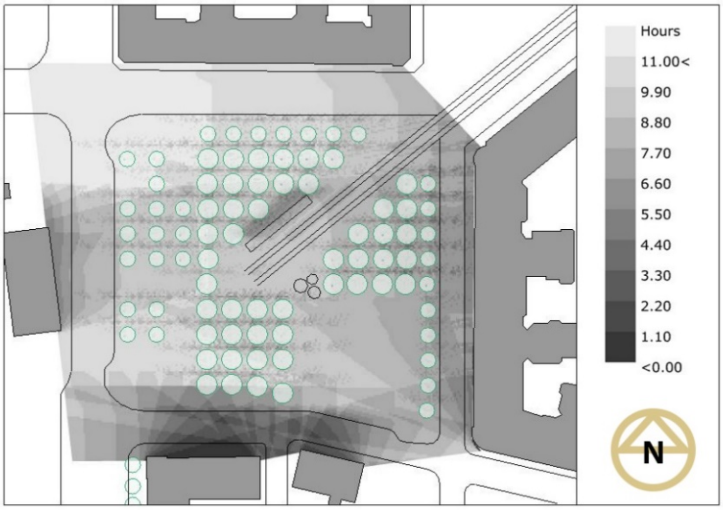


Figure 21: Direct sunlight hours for Clemenstorget on the 21st of March.

The site exploration with the drone helped to collect a set of pictures or captures to see the movement and the behavior of people partially. A composed image in Figure 22 was the result of the different captures. The limited autonomy of the battery and the low density of human activity on the ground made impossible to plot any heat map.

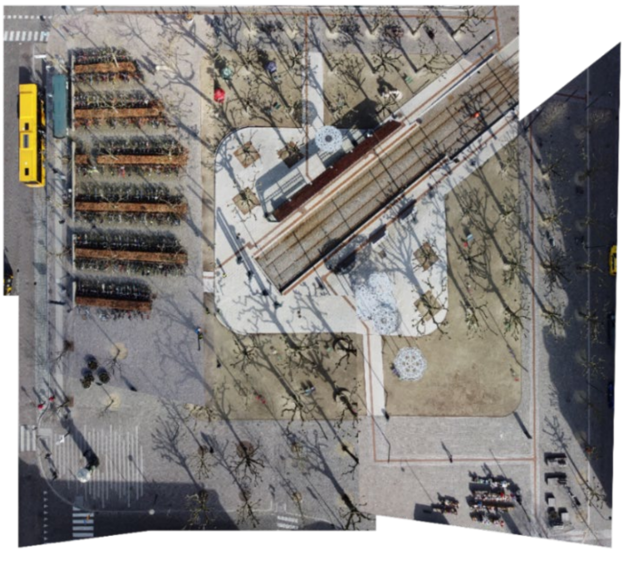


Figure 22: Collage of pictures from the drone flying over Clemenstorget the first day of survey.

In Table 4 it is shown the results for the Klux-h and the average illuminations with the comparison for the city baseline.

Table 4: Results for average illuminations and total yearly illuminations.

	Winter			**Summer**			**Year**
	Average Morning	Average Afternoon	Average Evening	Average Morning	Average Afternoon	Average Evening	Total year
Square	2 300 lux	5 700 lux	500 lux	18 800 lux	29 400 lux	11 400 lux	150 100 klux
City Baseline	3 500 lux	8 900 lux	900 lux	41 600 lux	45 400 lux	24 100 lux	339 900 klux
%	65 %	65 %	59 %	45 %	65 %	47 %	44%

3.1.3 Mäster Palms Torget (Helsingborg)

The results for *Mäster Palms Torget* reveled a similar performance for the DA and cDA metrics. On the other hand, the sunlight hours analysis showed a larger area with low access to direct sunlight on the south side. This is due to the height of the shopping mall *Söder*. The Figure 23 shows the result of the calculation. For this reason, most of the square was shaded while at the same hours, the others studied squares in Lund were lit by sunlight.

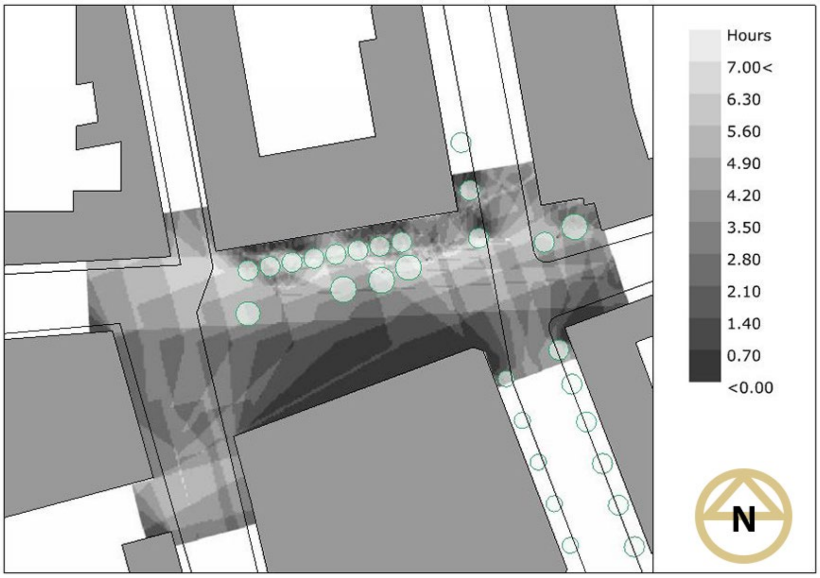


Figure 23: Mäster Palms Torget. Direct sunlight hours analysis on the 21st of March.

In the Figure 24, it is shown a terrace in this square. It was totally empty the day of the survey, during a sunny day. A recreation area with chairs and tables shown in Figure 25 was totally empty until the evening sun reached that part. In opposition, the benches of the entrance from the east were occupied throughout the whole day. See Figure 26. A parking for bikes occupied part of the area beside the eastern benches. In Figure 27 it is shown the parking occupying the sunlit area. A second terrace of a restaurant was located beside the same façade. No activity was observed in that terrace during the morning despite to be on the sun.

Figure 24: An empty terrace in Mäster Palms Torget. Figure 25: Sitting area with plastic grass. Pictures by Alejandro Manso.

Figure 26: Bench in the eastern side of the square. Figure 27: Parking for bicycles in the sunny area. Pictures by Alejandro Manso.

3.2 First survey results

3.2.1 Measurements

Vertical and horizontal illuminances were measured for every individual interviewed, including those who declined to participate in the interview. Results ranged from lower illuminances in the early morning to higher illuminances at noon. Vertical illuminances varied greatly as a function of direction, sometimes reaching higher levels than horizontal illuminances if the person was facing the sun. Sensors recorded horizontal illuminance. For the first day, the illuminance for the shadow sensor was more stable than for the sensor exposed to direct sunlight due to the intermediate sky and the clouds. The point-in-time measurements with the Lux meter for the resopondents did not match with the sensors' graph in Figure 28. These results correspond to the horizontal illuminances from the first day of survey in *Clemenstorget*. The 0 in the horizontal axis corresponds to the 09.40 p.m.

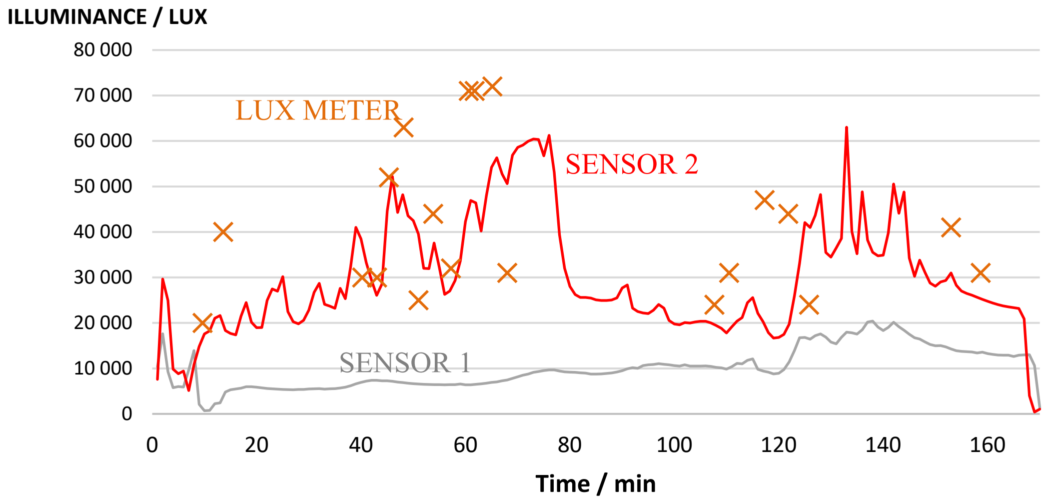


Figure 28: Measured illuminations the 18th of March during the survey.

The temperatures for the first day varied in a similar way to the illuminances. The sensor 1 started at 4 °C and reached a peak at the end of 8 °C. The sensor 2 started at 8 °C, reached a peak of 18 °C , dropped to 8 °C when it was cloudy and finally ended up in 12 °C.

It is important to choose the right location for the sensors and if possible, a place where people cannot have access to the sensor. The cast shadows of trees and furniture can also act as obstacle for the direct sunlight. It should be considered that the sun is moving on the sky because the shadows will change direction with the movement of the sun. Yet, the graph in Figure 28 seemed to follow an increasing tendency despite of the occasional fluctuations until noon. After 80 minutes of survey the sky was completely overcast for some minutes and this is reflected as a big drop in the illumination level. This was reflected in both sensors, especially the one placed on the sunny spot. Some minutes later, the sky was intermediately, and the illumination increased again during some minutes for finally, dropping again when the sky was once more completely grey.

The last day of survey in Katedralstorget with clear sky showed a more uniform graph for the horizontal illumination on the sensor (Figure 29). Here it is seen two points where the levels dropped, probably, because of interruptions by people passing by the sensor. The individual horizontal illuminations measured followed the same slope as the sensor's line. The offset between sensor and Lux meter came from the difference in height of the sensor location and people's eyes. The line for Sensor 2 shows a continuously increasing level, typical of a sunny day, which found its peak near to the noon when the survey ended. The measurements with the Lux meter showed a tendency line parallel, validating both outputs. Because nobody wanted to participate, more measurements with no interviews were recorded. That is the reason because in this graph it is seen a lot of points for the Lux meter where only five correspond to a successful interview for that interval of time.

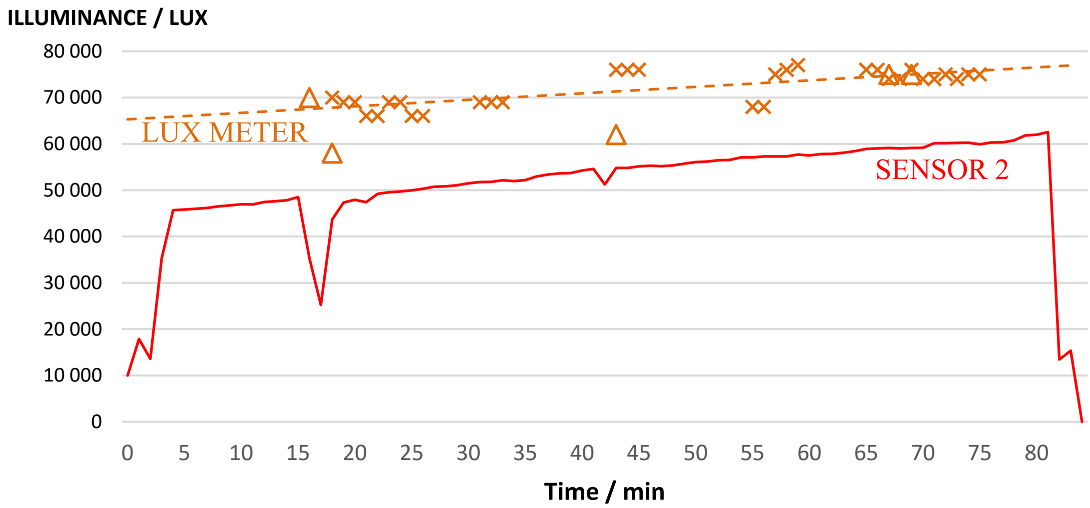


Figure 29: Measured illuminations the 30th of March during the survey. The triangles correspond with measurements during an interview.

In the previous graph the 0 for the horizontal axis corresponds to the 11.00 a.m. Here, the temperature went from 20 °C to 30 °C after around 80 minutes .The measurements did not include one of the illuminations. Unfortunately, one day in *Mäster Palms Torget*, the HOBO sensor located in the shade (Sensor 1) was stolen and its recorded information lost.

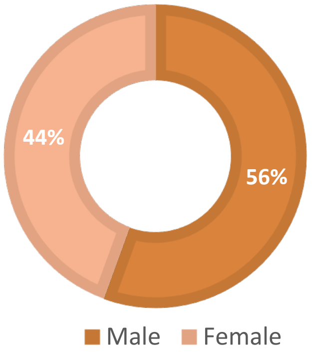
3.2.2 Questionnaires

In the four days of surveys, a total of 45 people answered the questionnaire. The conditions and total number of participants is shown in Table 5.

Table 5: Participants and conditions on the surveys.

SURVEY'S DATE	SKY CONDITIONS	SITE	NUMBER OF PARTICIPANTS	COMMENTS
18th April	Clear sky/intermediate	Clemenstorget	20	Drone flying
24th April	Overcast	Clemenstorget	10	
25th April	Clear sky	Master Palms Torget	4	Sensor stolen
30th April	Clear sky	Katedralstorget	11	

The distribution of the participant's age (Figure 30) and gender (Figure 31) are represented in the following graphs. Among all the respondents, a high number of adults above 55 years participated, much than the other ages. This was probably due to the selected days during which the interviews were performed on weekdays. In addition, as the observer could appreciate, the elderly was more likely to establish conversations and participate.



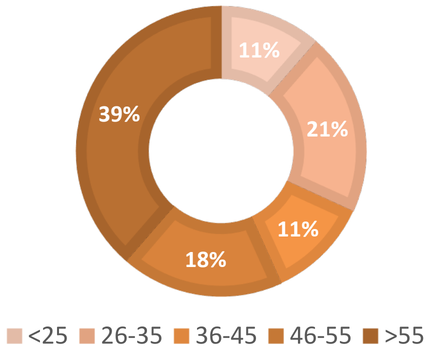


Figure 30: Percentage of participants divided by age. Figure 31: Percentage of participants divided by gender.

The distribution of gender was more balanced, with only a small difference of more men than women. Most of the respondents were local, residents in Lund or the surrounding areas. Some residents came from other regions of Sweden, and only a few people were non-locals.

As it is shown in Figure 32, there was a large number of responses with an optimistic judgment of the solar access and daylight conditions. They indicated "*strongly agree*" for almost all the questions. This is especially particular for the last four questions. Just a few *No response* (NR) answers were collected.

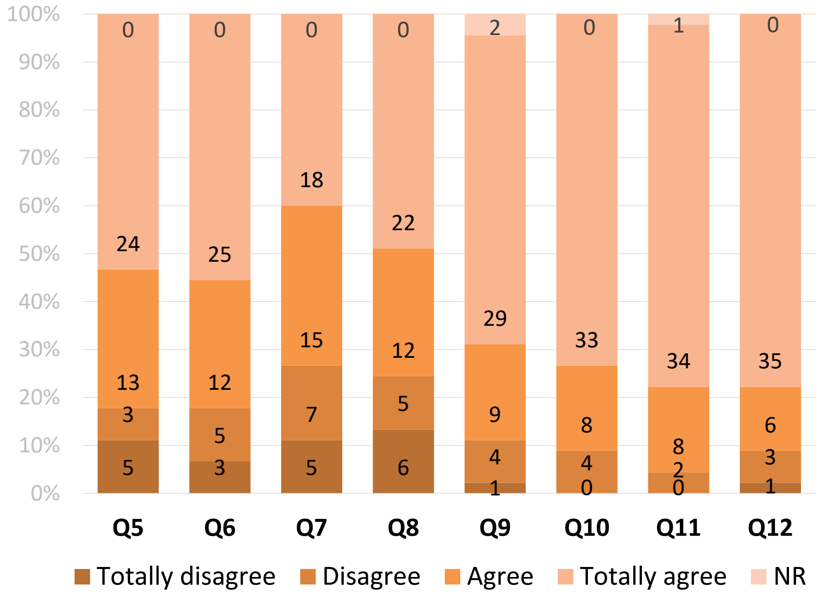


Figure 32: Responses to questions related to solar access (Q5-Q8) and daylight (Q9-Q12).

Furthermore, the respondents who indicated to be there for pleasure were only three for the first day as it is seen in Figure 33. There is a clear bias given from activities (people waiting the tram) and another bias from location of the benches. Yet nobody actively chose the darkest areas.

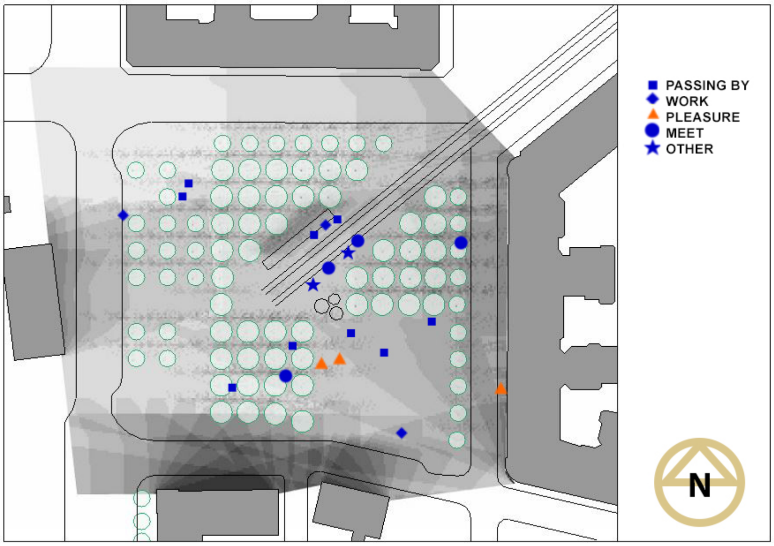


Figure 33: Distribution of respondents from the first day in Clemenstorget.

The first graph in Figure 34 shows all the results collected in the first survey. In this graph, for the horizontal axis it was used the horizontal illumination recorder with the Lux meter.

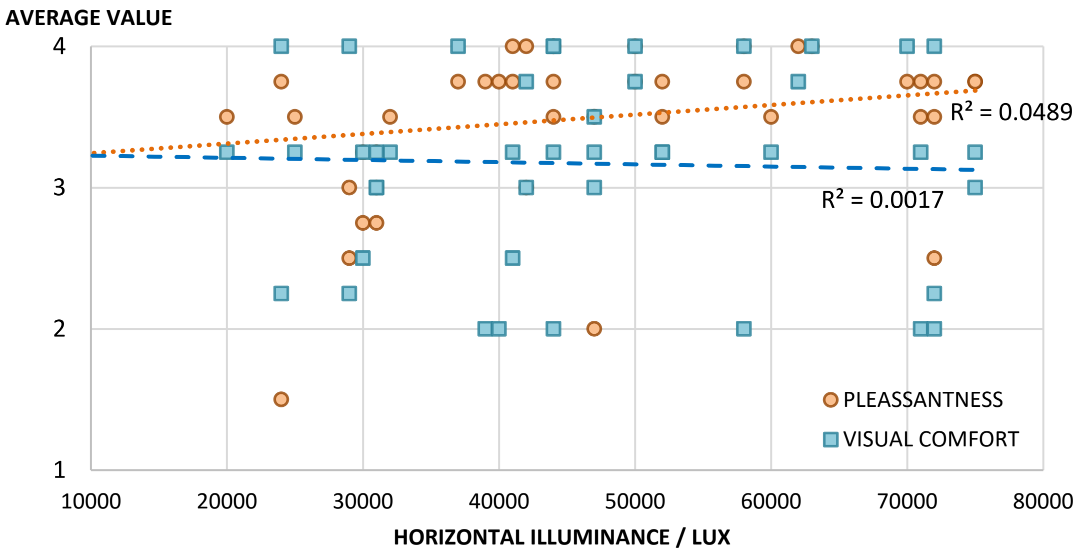


Figure 34: Correlation for all the respondents.

In Figure 35 it is shown the results for the whole survey if the vertical illumination is used in the horizontal axis of the graph. In both graphs for all the respondents collected, the R^2-value is almost 0.

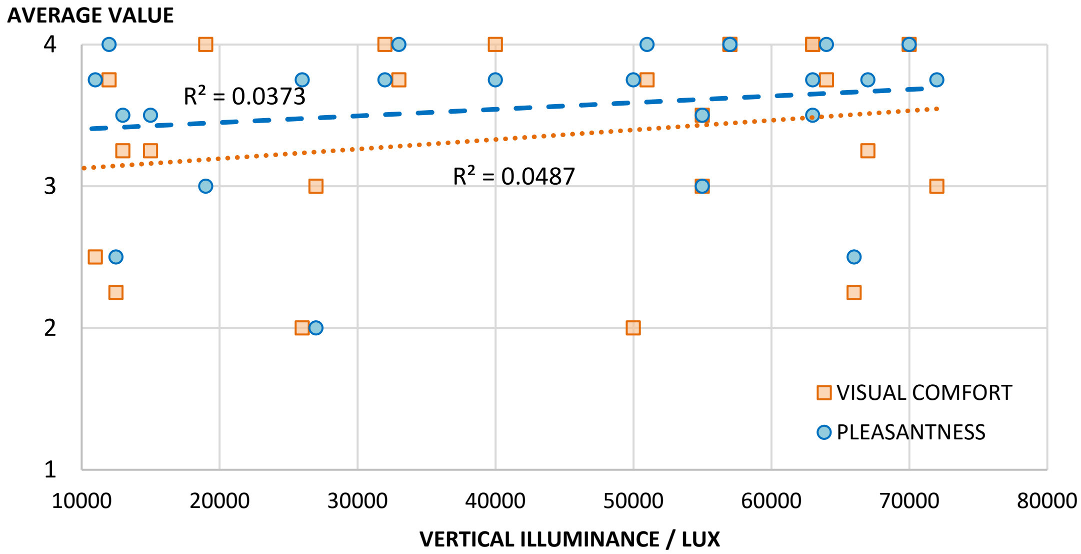


Figure 35: Correlation for all the respondents.

Similar results were found if the results from only the clear sky days were isolated. The R^2-value is almost 0 for both horizontal measurements (Figure 36) and vertical measurements (Figure 37).

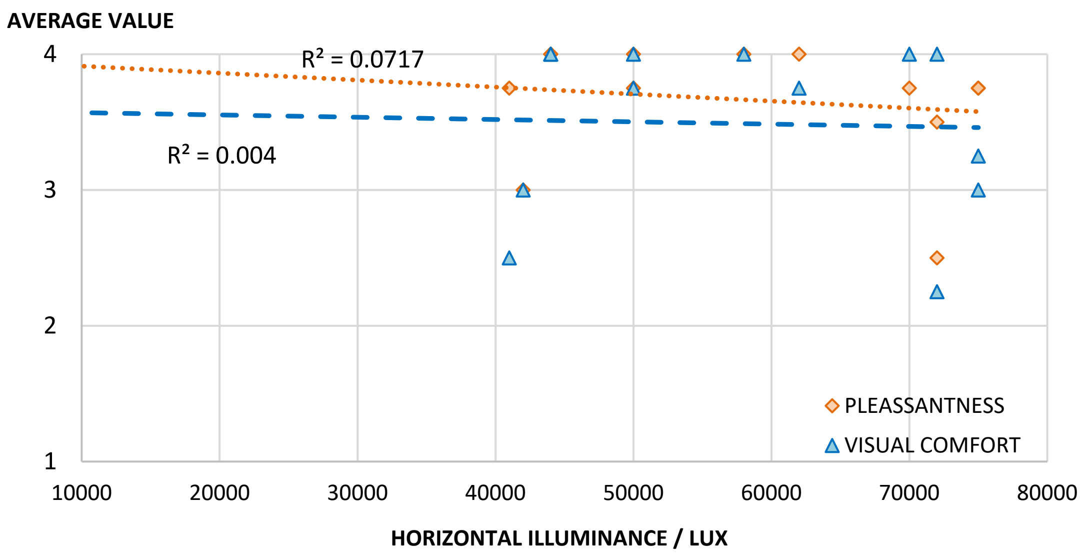


Figure 36: Correlation for only respondents under a clear sky day.

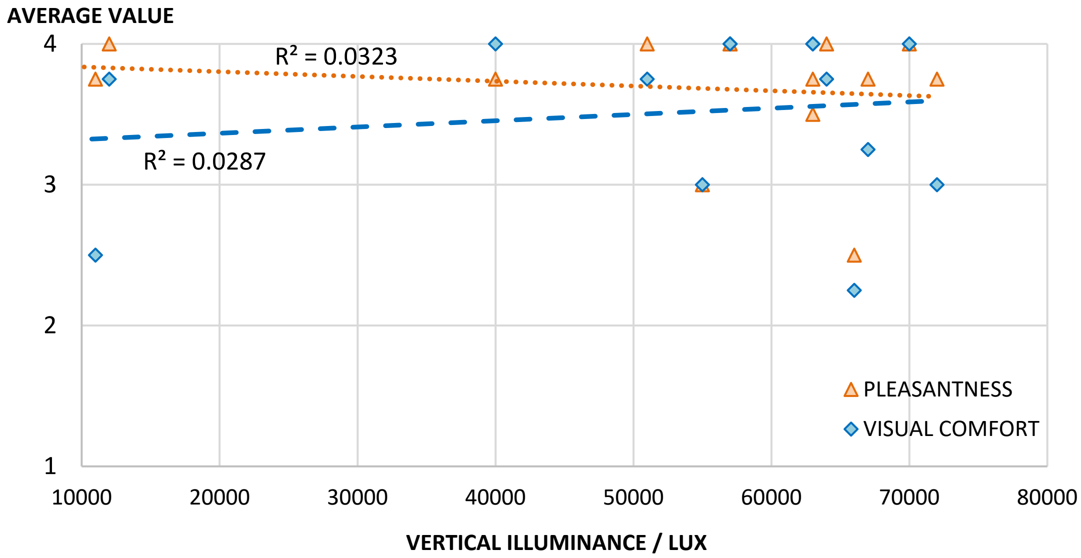


Figure 37: Correlation for only respondents under a clear sky day.

The results on the graphs above tend to be dispersed and not follow a pattern. Putting together the results from a clear sky, overcast sky and intermediate sky days did not result in a higher correlation, but a disperse cloud of points. On the other hand, there was a weak correlation for pleasantness with illumination levels in Figure 38 below these lines. This weak correlation for *Pleasantness* includes samples from overcast sky and intermediate sky conditions.

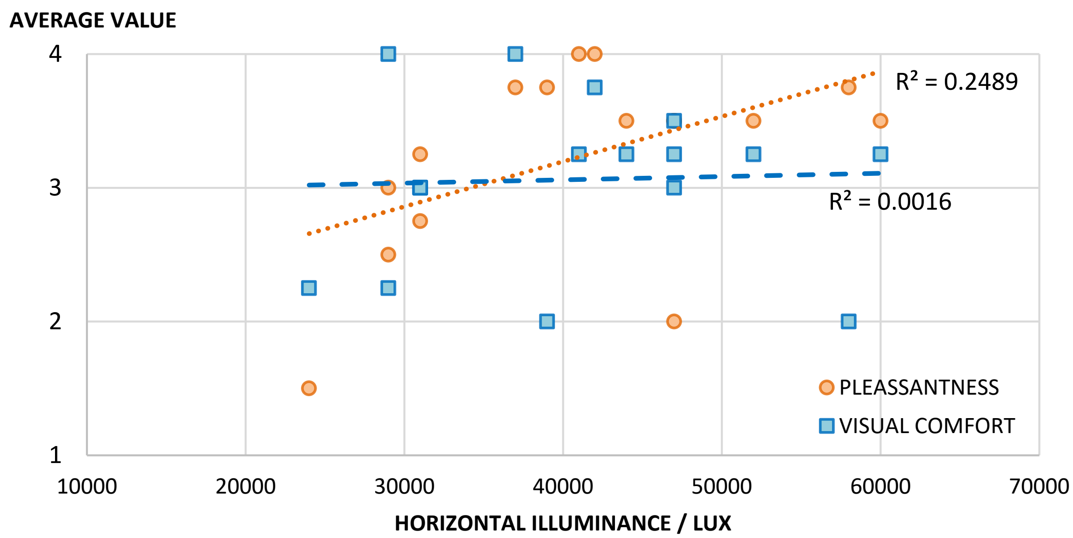


Figure 38: Correlation for overcast sky with horizontal illuminations.

If some samples were discarded because the observer considered this reasonable, the correlation became slightly higher. In a larger survey questionable results might be showed as outliers in the graph but having so few samples it seems to be a good approach to remove the results from people that, under the interviewer judgment, they offered a misleading response. For instance, a man during the interview was laughing and looked at his friends before to answer each question. Finally, all the results remained in the graph to avoid any kind of bias from the interviewer and because there were no great differences after removing misleading responses.

At the same time, a weak correlation was found for optional activities like eating, reading or smoking during first survey. Figure 39 shows this finding.

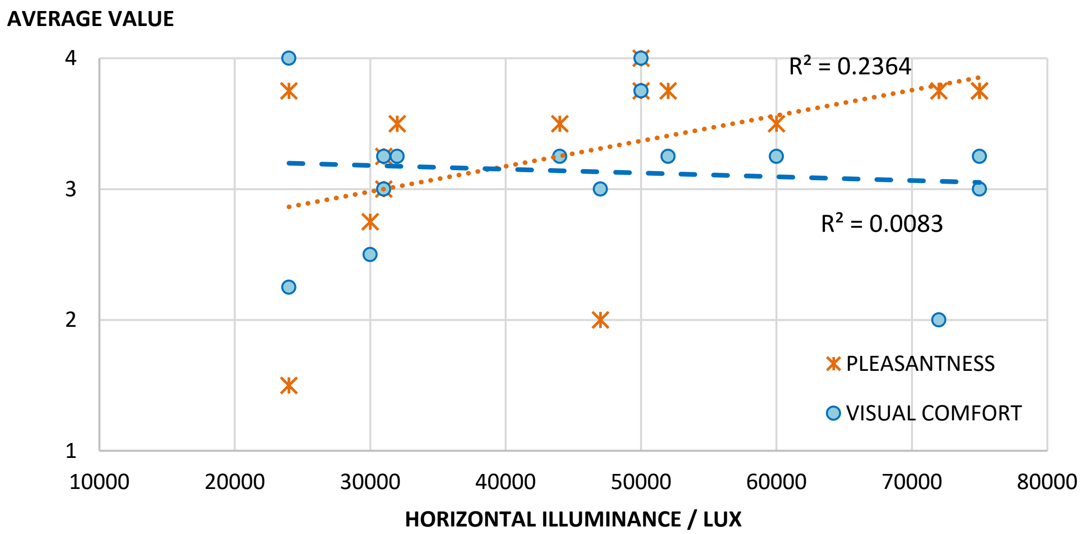


Figure 39: Correlation for optional activities with horizontal illuminations.

Among all the people interviewed, there were many people passing by or waiting for public transportation or for someone else. However, most were standing. Around 40 % of respondents were passing by. Around 75 % of the people observed and account were in a sunny spot or walking toward the sunlit area, even if they have not participated in the interview. During the survey, it was observed more people in groups or having an active social engagement when the day was warm and the sky clear.

Although the results for main questions Q5 to Q12 were not so helpful to find a correlation with the illuminance levels, the comments given by the respondents they did help to understand more what people think.

- When everybody was sitting in the sun with clear sky and a warm temperature, a woman with a baby spent a long time in the shade. She indicated that she preferred the sun, but was thinking of the baby's health, who should not be exposed to the sun. Some people joined her later and hold a conversation. One man stood in the shade closed to the first woman and a second woman kept some distance to clearly, stand in the sun while still have some social proximity.

- A couple of people mentioned on the first day when the sky was partially cloudy that they preferred some intermittent intervals of sun to be outside than nothing. They only needed this irregular solar exposure to be satisfied outdoors instead of staying at home as they mentioned.

- "*I would like to be in my private garden, but as I need to come to city for grocery, so I want to find a good place where to sit for a while in the sun*". An old woman said in one of the interviews.

- Several people mentioned that they found pleasant and comfortable to get irradiation directly on the face, but not on the eyes.

- A couple of Asian students said: "*It is disgusting, the direct sunlight (irradiation) made my skin itch. I do not like the irradiation on my face*".

- A lot of elderly mentioned the importance of having spaces where to rest and have a sun bath, or just sit and talk to each other during daily tasks as for instance, going to the grocery. A few highlighted the extreme value of this option after the pandemic. Others indicated that they have been voluntarily in lockdown for their own safety and now the use of public spaces under the first sunny days of spring was a great experience.

- "*Now is the time for being as much as possible in the sun, but in summer I would search for a place under the shadow*". Said an elder woman.

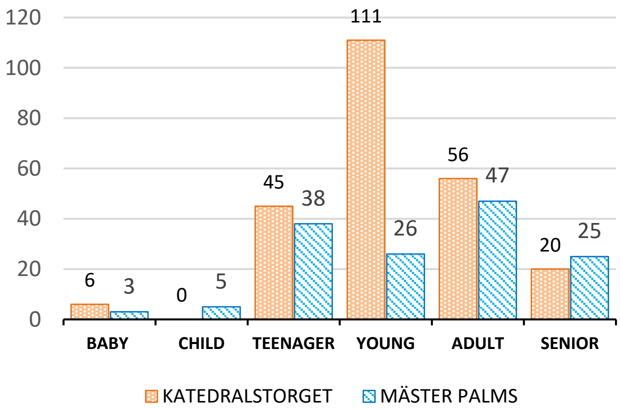
- Some people said statements as "*Always is a pleasure to see the sun", "The more sun, the better".*

- "*The sun is not the best these days, but still OK*". Said a man during the interview. Still, he gave the highest score for all the questions.

- *"When spring begins and it is sunny, we do coffee break every day in these benches every day so our neighbors can join and enjoy together instead of staying home"*. Said an elder in a small group of people having a coffee together.

3.3 Second survey results

The observation took place in the middle of April. More days of clear sky were found, and temperatures had raised up in comparison with the first survey. After the observations include in the second part, a total of 236 samples for *Katedralstorget* and 143 for *Mäster Palms Torget*, was recorded. The distributions of gender and age is shown in the following figures (Figure 40 and Figure 41).



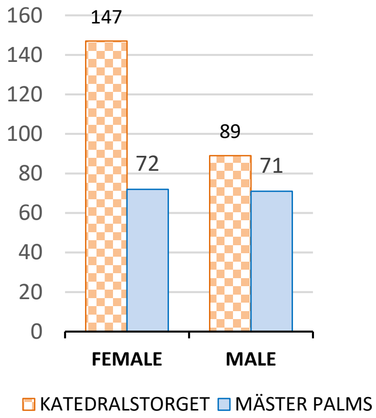


Figure 40: Number of participants divided by age. Figure 41: Number of participants divided by gender.

Figure 42 represents the distribution for both squares of the people socializing somehow and who was in a passive attitude. As it is show, around 2/3 of the users were in company like couples, friends or families.

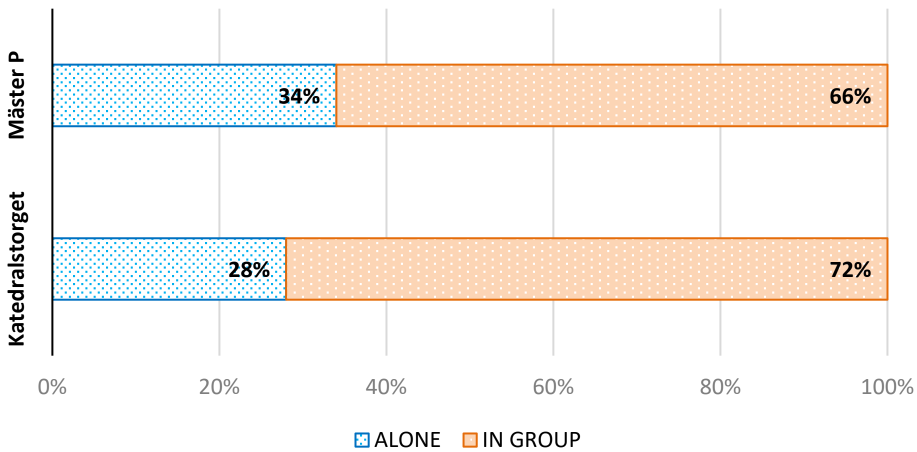


Figure 42: Comparison: observed people by square and social condition for clear sky days.

The next graph, in Figure 43, shows percentages of people found with direct solar irradiation and percentage of people in the shade. Most of the people chose sun, but still a small portion stayed away from the sun.

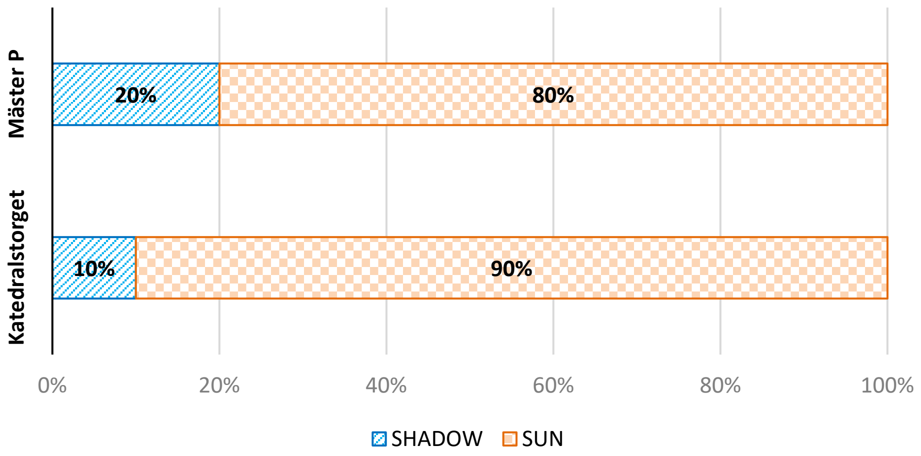


Figure 43: Comparison: observed people by square between shaded and sunny spot for clear sky days.

In the following figures, different behavioral maps for *Katedralstorget* are shown. The distribution of people and their social engagement changed along the day. General speaking, most of the people chose to sit on the benches in the sunny side beside the cathedral. Minor number of people were seen on the benches on the opposite side of the square. Most of the people socializing were seen on the sunny side. Nevertheless, in the morning people were more even distributed and the sun reached most of the seating options (Figure 44).

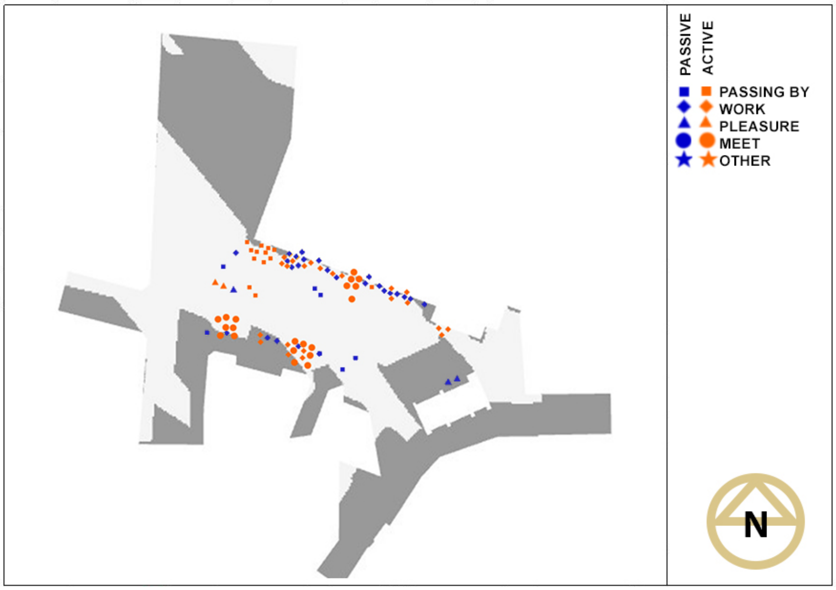


Figure 44: Behavioral map for Katedralstorget during clear sky day from 10.00 a.m. to 12.00 p.m.

At noon people were already choosing the sunny side and sometimes the shade if there was any available space in the other side (Figure 45). At noon was when more socially active people were observed.

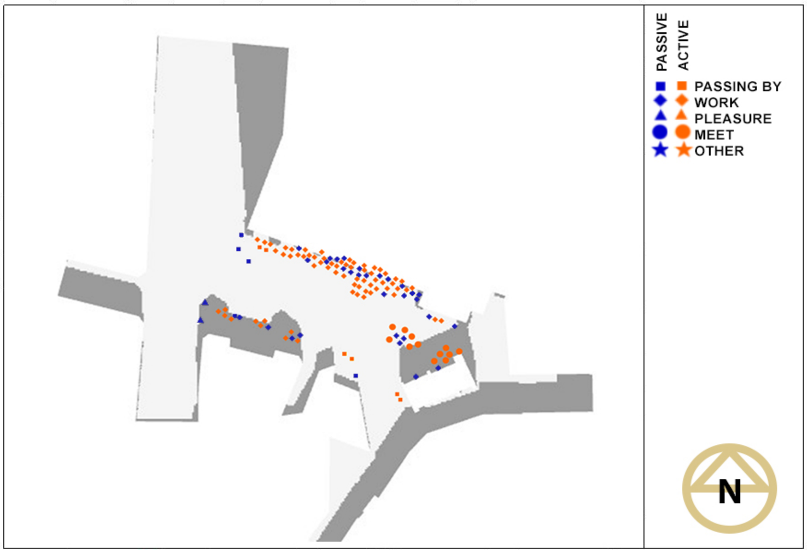


Figure 45: Behavioral map for Katedralstorget during clear sky day from 12.00 a.m. to 13.00 p.m.

In the afternoon, the trend continued, and people still preferred the sunny side (Figure 46). Many of them were people that stayed for longer than one hour socializing. New people came and many others left during this time.

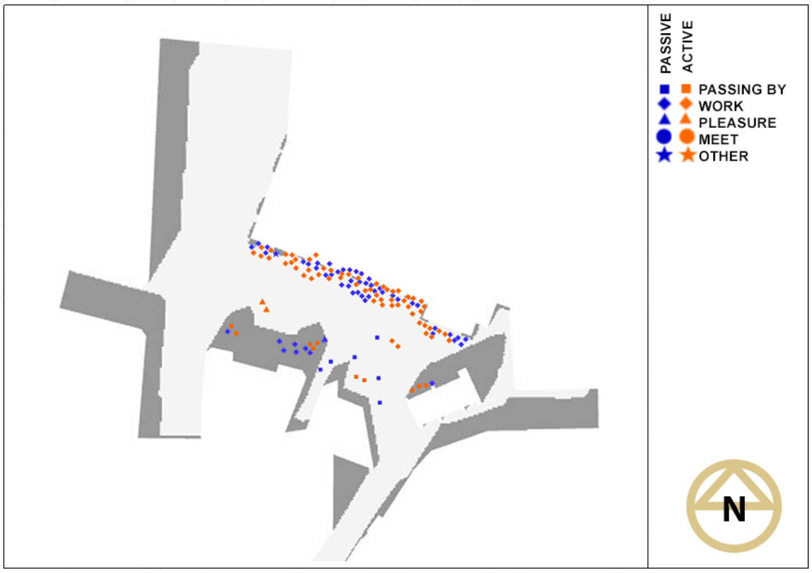


Figure 46: Behavioral map for Katedralstorget during clear sky day from 13.00 a.m. to 15.00 p.m.

In the early morning hours, *Katedralstorget* was not as busy as later hours. A few people were crossing the square or arriving at the *Forum* building. Most of the pedestrian's flow was going along the adjacent street, from north to south. Some people used the bicycle parking on the north façade of the *Forum*. In the presence of the sun, there was always someone on the benches beside to the cathedral as it is shown in Figure 45, where the wind was negligible. The other spaces were empty most of the time in early morning. There were also many people waiting for others or walking with their dogs. More people with pets were observed on clear sky days in mid-April compared to the dates near the equinox.

Figure 47: People sitting on the benches in Katedralstorget under a clear sky day in the morning. Picture by Alejandro Manso.

In *Katedralstorget*, the flow and the number of people using the spaces increased at lunch time for at least a couple of hours. Many people were observed eating or having some kind of snack or drink. The benches were occupied for longer periods of time. Portable chairs were often used for seating when the groups were large or for other functions as table, footrests, etc. At *Mäster Palms Torget* the number of people in the morning was just a few. Especially when most of the square is shaded and the sun only reached the northern side.

Functionality also played a role in how people could use the outdoor public space. For example, in *Katedralstorget* the bikes were parked in a lost space in a recess of the *Forum* façade where, according to the shadow analysis there was almost never direct sunlight. Therefore, it is difficult to assign other uses to this place, and the parking did not limit the solar access of the users. On the contrary, in *Mäster Palms* the parking lot occupies one of the most privileged places where there were more hours of sunlight. This eliminated a valuable area for solar access. In *Clemenstorget*, the largest parking was in the west side and was thought for the people using public transport, but it occupies one of the best places for solar access. Fortunately, there is a *White Arkitekter* project underway to refurbish the square. In the second stage of this project, the street on the west side of the square will be closed to traffic, connecting the public space to the train station. The most remarkable aspect in this solution is the displacement of the bike parking away, opening an opportunity for new uses of this portion of public space

4 Discussion

4.1 Did the questionnaire work?

The extremely positive evaluation of people showed a general satisfaction with the conditions although did not cast more light to the research questions. The interviews occurring after a long dark winter may have some impact in people's evaluation. There are many variables involved and this makes difficult to perform such kind of surveys in the public space. The limitation of the questionnaire made some respondents who were sitting in the shade value solar access in the same way as those who sat in the sun. Moreover, although the language was simple, it was difficult to know exactly if people really comprehended what they were asked. Despite having some similar question for daylight and solar access, most of the interviews were conducted using the Swedish translation. This was slightly different, separating more clearly daylight from solar access.

Something notorious and another important limitation was the fact that people always modified their behavior during the interview and maybe this affected their perception of solar access in that moment. Moreover, a lot of respondents were in a hurry as the interviewer perceived. Therefore, some of them gave unreliable answers or extremely optimistic answers without taking time to think. Others showed an evasive attitude despite accepting the participation in the survey. Furthermore, the participation along the days decayed with the best weather conditions, so it was interpreted that the better the weather, the less chances were given by the people to the interviewer.

As it was read in the first chapter of this paper, other studies succeed in correlating physical measurements with subjective evaluations from questionnaire-based interviews. However, they were related with microclimate when point-in-time measurements accompanied the interview or with yearly simulations when daylight was studied.

Despite the lack of correlation for the Likert scale questions, giving the option of comments still offer some valuable information. The comments offered some qualitative information which may be useful, like opinions about a square, preferences for solar access or habits. This information offers to the urban planners a tool to know more about people's preferences in the public space related to solar access.

Another inherent weakness to this study was based on the fact of work with the same site for several days. The respondents were somehow warned and alert, so they tried to avoid the interview. Since people were more reluctant to participate in the survey, other options could be explored to encourage participation. Finally, it was difficult to find what was the correct number of respondents for the first survey, but the available time with the desired weather and sky conditions was limited.

4.2 The sun as a socializing booster

Both surveys captured the same perception about the more sociable behaviors during clear sky days. People decided to socialize more on sunny days, and optional activities were done in pairs or groups more often. When conditions were optimal, these groups also had more social interactions as it was observed. This made people less willing to participate in interviews. This is seen in Table 5: for the clear sky day in *Katedralstorget* the participation dropped widely compared with the first days in *Clemenstorget*. This is true for all the studied squares, but more evident whenever more solar hours and more sunlit area was available. This result confirms the previous observations about the increasing in social activities in (Gehl,2010), when an outdoor space offers the optimal frame for them.

On the other hand, some people, especially large groups, discarded locations with partial shadows or near the shadows. Partial shadows such as tree branches, trunks or other objects in the urban environment are enough for some people to discard such places to sit for a long time. Places where the shadows from surrounding buildings were about to reach them were also discarded for large groups.

Other aspects that may influence people' behavior during observation can only be discussed hypothetically. Some people lay down on warm surface or prefer places where it was not blowing. Because this was not object of study in the survey, not much more could be extracted. However, the observer comments offered a small interpretation. People use all the available options in a public space when they can choose, but there was a clear favorite place where microclimate may be slightly different. Further research including temperature and wind speed would be able to clarify this behavior when people show a clear preference for one area in a square even if the whole space gets direct sunlight.

4.3 Future research

The goal was to assist urban planners to have a better understanding of solar access in the outdoor space. The research aims to provide basic information about people's evaluation of solar access but there is still a lot of other potential studies to contribute to this purpose.

For future research, a different questionnaire should be designed to correlate subjective impressions with point-in-time illuminance values. It would be interesting to try the method for the autumn equinox and compare with this first result. On the other hand, there is still the option of longer explorations. Surveys throughout the year could be interesting but were not included in this study due to the limited period available for the research. Including thermal comfort, expectances of solar radiation and brightness and long-term subjective impressions of the space as other previous studies has done could be an interesting idea for future investigation in south of Sweden. This was already done with some positive results in other parts of Sweden (Yanga et al., 2016) and other countries (Lam et al., 2020).

Qualitative and quantitative observations together with open questionnaires could give more clues about people's subjective evaluation and their perception of urban spaces. Thus, these methods are recommended to complete similar studies as the previous paragraph mentioned.

It would be also interesting to analyze the before and after of some changes in the urban fabric or other minor interventions in public spaces in the studied context of Sweden, especially for winter conditions. This will not only show how well a project was thought in terms of solar access, microclimate or functionality, but it could also result in more findings around how people evaluate solar access. For example, the method for the second survey could be applied in *Clemenstorget* to analyze the upcoming second stage of the square renovation by *White Arkitekter*.

5 Conclusion

The study was carried out as a qualitative survey with a questionnaire-based interview and some observation together with some technical measurements for two representative squares of Lund, and third from Helsingborg. The results for factors as visual comfort and pleasantness related to solar access and daylight had no correlation with physical illuminance values. The methodology was probably wrong and the reason behind the total lack of correlation. Later, a second survey was carried out for the same squares to complete the study. It was a mixed survey based on qualitative observations of activities and behavior of space users and a quantitative observation for factor as age, gender and time spent on the space.

The simulations showed a similar performance for the squares with a similar size when daylight metrics where studied. However, the results for direct sunlight hours simulation were different for the three spaces. *Katedralstorget* had much more surface with a high access to direct sun in comparison with *Mäster Palmas Torget. Clemenstorget* obtained more hours because of the size and the absence of foliage after winter for the spring equinox. There was not a strong connection between the daylight simulations and the questionnaire responses, but the simulations helped to explore and know the sites before the surveys.

To the question: "*How do people evaluate solar access in public spaces and how do they behave under the specific conditions for the chosen space?",* the answer would be that people usually choose areas with direct sunlight for optional or social activities. In opposition, the direct sunlight was less relevant for necessary activities like passing by or waiting. Even so, some still preferred to be in the shade for certain activities or when they did not foresee spending much time there (e.g., old man resting, checking phone while waiting for another person, etc.). The observations revealed a clear willingness to be more socially active and interact with more people under direct sunlight. In some places with less hours of sun per area, people showed similar behaviors. In *Mäster Palmas Torget* in Helsingborg people chose to stand up for waiting in the sun, although they did not prefer to wait in the shaded areas, where seating options were, or the benches in the sun.

How do the evaluation and the behavior relate to the physical solar access? There was no correlation with the level of illumination, although there might be a slight relationship between illumination and pleasantness under cloudy or overcast days, especially for optional activities. People chose places with direct sunlight, but some people discarded places with partial shadows or places close to shadows when the shadow could reach them during the expected time to stay.

And finally, "*Which other factors (function of the space, wind exposure, street furniture, etc.) affect or interfere in the perception of solar access?*". Other factors such as thermal comfort linked to wind may have affected people's preferences, although this research did not study microclimate conditions. More studies should be done to corroborate this where wind speed and temperature were included. Offering variety of seating options and flexible solutions encourage people to spend time outdoors if this furniture is placed in sunny spots but, protection from wind should be available. The functions of the space can affect the availability of optimal places where to locate urban furniture or other potentials features for people interaction during sunny days.

Humans cannot change the climate or choose the weather conditions. In this part of Sweden there are many cloudy and rainy days, but there are always ways to make public spaces more attractive. It is a matter of taking advantage of the solar potential that is already there, when it is there.

Appendix A

Number		Date/Time		

<u>Before you start, here are some useful definitions to help you answer the questionnaire:</u>
<u>(Innan du börjar, här är några användbara definitioner som hjälper dig att besvara frågeformuläret).</u>
- "**Daylight**" refers to light including sunlight and diffuse or reflected light.
- "**Sunlight**" refers to direct light from the sun. Direct light and sunlight are synonymous.

Frågorna handlar om hur du upplever platsens tillgång till sol-och dagsljus. Med solljus menar vi här det direkta ljuset från solen och med dagsljus menar vi allt ljus inklusive det reflekterade ljuset.

This will be anonymous. First, some basic information about you. 😉
Detta kommer att vara anonymt. Först, lite information om dig.

Q1	**Age** Ålder	≤25 years	26-35 years	36-45 years	46-55 years	≥56 years
Q2	**Gender** Kön	Male		Female		Other
Q3	**Are you a local or a tourist?** Är du bosatt eller turist?	Local			Tourist	
Q4	**Reasons for visiting this place** Vilka anledningar har du för att besöka den här platsen?	Passing by	Work	Pleasure	Meet somebody	Other

Now it is time for the questionnaire! 😉 Nu kommer det riktiga frågeformuläret!
1= Strongly disagree (Håller inte alls med); **2= disagree** (Håller inte helt med); **3= Agree** (Överens/Instämmer); **4= Strongly agree** (Mycket överens/Instämmer helt). **N= I would prefer not to answer** (Jag föredrar att inte svara).

Q5	**Sunlight is bright enough for the activity I am doing now.** Det direkta solljuset är starkt nog för aktiviteten jag ägnar mig åt nu.	1	2	3	4
Q6	**The direct light from the sun is pleasant right now.** Det direkta solljuset är bekvämt just nu.	1	2	3	4
Q7	**The current level of sunlight encourages me to spend more time at this location.** Den nuvarande solljusnivån får mig att vilja spendera mer tid på den här platsen.	1	2	3	4
Q8	**It is tolerable to have direct sun in my eyes / face right now.** Det känns acceptabelt att få direkt sol i mina ögon / i mitt ansikte just nu.	1	2	3	4
Q9	**Daylight here seems appropriate for what I am doing right now.** Dagsljuset här verkar passande för vad jag gör just nu.	1	2	3	4
Q10	**Daylight in this space looks pleasant right now.** Dagsljuset på den här platsen ser trevligt ut just nu.	1	2	3	4
Q11	**The level of daylight seems bright enough in this place right now in general.** Dagsljusnivån verkar vara allmänt tillräckligt på den här platsen just nu.	1	2	3	4
Q12	**I am satisfied with the daylight in this place right now.** Jag är nöjd med dagsljuset på den här platsen just nu.	1	2	3	4

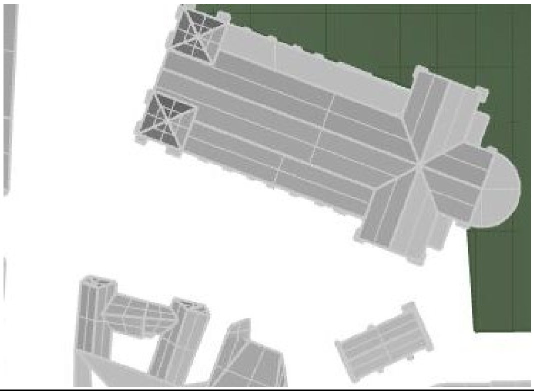
COMMENTS:

Appendix B

OBSERVER

Number	
Time	
Horiz. Illuminance	
Verti. Illuminance	

Alone	In group



Activity

Sitting	Walking	Standing	Lying down	Other
	A to B			Other…
Snack/Beverage		Snack/Beverage	Snack/beverage	
Eating	Pleasant walking			
Socializing	Socializing	Socializing	Socializing	
Looking to the telephone/ visual task	Looking to the telephone/ visual task	Looking to the telephone/ visual task	Looking to the telephone/ visual task	
Just watching/waiting		Just watching/waiting	Just watching/waiting	
Other	Other	Other	Other	

Exposure

Sunny place	From sunny loc. to shaded loc.	Other	**Shaded place**	From shaded loc. to sunny loc.
Looking to shaded place			Looking to sunny place	
Looking to sunny place			Looking to shaded place	

Does he/she talk with others during the interview?

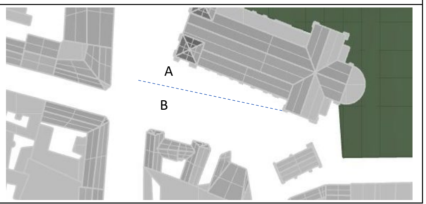
yes	no

Observed a reason to discard the subject?

yes	no

Appendix C

Day	**___ April**	**Site**
Sheet	**1 2 3 4 5 6 7 8 9 10 11 12**	
Period (hh.mm/hh.mm)	__.__ / __.__	
Ob. AREA	__	
Illuminations (sun/shad)	/	
Sky condition	Clear / Int. white clouds / Int. grey clouds / Overcast	
Wind	No / Windy / Very windy	
Interruptions_?		
Notes		



BASIC							PHYSICAL ENGAGEMENT						SOCIAL ENGAGEMENT					COMPLEM. ACTIVITY										
iD	Age B/C/T/Y/A/E	Gender (M/F)	SUN/SHA/**OV**ERC. /IN **BET**WEEN	IN (hh.mm)	OUT (hh.mm)		Standing	Sitting	Walking	Lying	Hanging Out	Other	Passive	Active Talking	Physical contact	Group ID	Meet/Together	Eating	Snack/beverage	Smoking	Reading	Music	Telephone	Sun bath	Eng. With feature	CHA. ENVmt.	Protection for sun	Other
1																												
			Note			Note							Note					Note										
2																												
			Note			Note							Note					Note										
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			Note			Note							Note					Note										

Appendix D

The protocol for the second survey followed for the assessment are shown in the following lines:

1 The day before.
- 1.1 Check the weather forecast.
- 1.2 Prepare camera and charge battery.
- 1.3 Print at least 10 sheets for having at least one for each 15 min of observation.

2 The day of the observation.
- 2.1 Arrive at place 10 minutes before the start time.
- 2.2 Search for a good position in every zone of observation if not was marked before on a map. The positions should have control over the whole part of the square. If it is necessary.
- 2.3 Take some pictures if there is something unusual or worthy to mention.
- 2.4 Prepare one sheet and the start the counter clock in the telephone to keep control of timing.
- 2.5 Fill out the conditions for the interval (sky condition, zone designation, time frame of the interval, sheet’s number, etc.).
  - 2.5.1 Day of survey.
  - 2.5.2 Sheet’s number. The counting will start over for each day of observation.
  - 2.5.3 Interval of time to remember the hour and make easier to calculate length of staying for every sample.
  - 2.5.4 Illuminations if it is interesting.
  - 2.5.5 Sky condition
  - 2.5.6 Wind exposure
  - 2.5.7 Interruptions. Note every incident that could be interpreted as a disturbing event on normal people’s behavior.
  - 2.5.8 Note other interesting events or perceptions over the square or for that day.
- 2.6 Start observation from left to right as a preliminary way to keep some order. However, more people will drop in the observed zone, so this step is not rigid.
- 2.7 Fill the basic information first, the physical engagement and social engagement. Then, the complementary activities. Also fill the notes for each category to record useful qualitative data.
- 2.8 Especial attention to those who interact with other people. Someone may join later a group or abandon it. Also, people who change momentously the physical engagement are not recorded as different.

2.9 When the 15 min interval is out, move to the other part of the square and start again the steps 2.4 and 2.8.

Once finished the observation, the observer should transfer the data from the paper sheets to the computer meanwhile information and observer’s experience is fresh. It should be the same day.

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