VISUAL LINK BETWEEN STUDENT RESIDENCES AND THEIR OUTDOOR ENVIRONMENT

Reinis Melgalvis
Faculty of Architecture & the Built Environment, Delft University of Technology
Julianalaan 134, 2628BL Delft

ABSTRACT

The significance of visual quality factors, such as daylighting, outdoor views, and privacy, in residential architecture, is widely acknowledged. However, these factors are not always explicitly considered during the design process. To ensure their quality, it is crucial to address them in the early stages of design, as they are primarily determined by the spatial configuration. This study aims to examine the use of a parametric evaluation model to evaluate visual quality in student dwellings and inform design decisions. A literature review and interviews were conducted to identify visual quality parameters, and a parametric evaluation model was developed through experimentation. The results show that the model can provide clear visual data on evaluated parameters, such as daylight illuminance, overexposure, and view angle, in the form of heatmaps and number tags to highlight areas that need improvement and to compare different design alternatives.

KEYWORDS: *Student dwellings, design optimization, visual quality, performance evaluation, design decision support*

I. INTRODUCTION

By designing buildings, architects create space that shapes the way we live and work. Creating space is essentially a process of configuration, as through the placement of design elements such as walls, floors, and ceilings, we create boundaries between indoors and outdoors, as well as internally, making a division between different functions. Configuration of space is traditionally done intuitively, as the human mind effectively handles it this way. However, as this approach is implicit, it can be difficult to analyze and discuss the quality of the designed space (Hillier, 1998)

Given that over half of our lives are spent indoors (Höppe & Martinac, 1998), the quality of this space is essential for our physical and mental well-being (Bello et al., 2018). Although spatial quality is a rather subjective topic, it has been addressed in academic research before. Acre & Wyckmans (2014) have identified privacy, views, and lighting as important factors that are perceived by residents in relation to spatial quality. In research from 2017, noise, daylight, privacy, and greenery have been identified as relevant (Tibesigwa et al., 2017). Lai et al. (2009) emphasize thermal comfort, acoustics, lighting, and air quality as significant.

While construction details and materialization play a larger role in aspects of spatial quality such as acoustic, thermal, and air quality (Gramez & Boubenider, 2017), visual quality aspects such as daylight, view, and privacy are predominantly determined in the configuration of space. Therefore, these aspects must be explicitly addressed in the early stages of design to ensure their quality. However, the conceptual design stage, which has the most impact on design quality, is relatively short (Bogenstätter, 2000). Consequently, the feedback required for informed decision-making should be provided with minimal input so that multiple design alternatives could be compared efficiently and explicitly. Performance evaluation models can achieve this, while their implementation is predominantly adopted for environmental analysis rather than spatial quality evaluation (Yan & Kalay, 2005).

This paper investigates how the parametric performance evaluation model of visual-spatial quality can enable more informed decision-making in the early stages of design for student dwellings. The first section will investigate the perception of visual-spatial quality and address the parameters that affect it.

Subsequently, Architectural design elements that affect visual-spatial quality will be identified. Finally, a parametric performance evaluation model will be built through design process, to test the relationship between design elements and visual-spatial quality parameters in practice.

II. Method

This research is divided into three parts, progressing from a more theoretical beginning where the spatial quality and its factors will be defined, to a more practical application where a parametric evaluation model will be built. Various research methods will be utilized in each part of the research.

Firstly, to gain a deeper understanding of the aspects of visual quality, a literature review will be conducted to study existing theories of visual quality in residential spaces. This will be supported by primary research through interviews with students to gain further insights into their perceptions of spatial quality and the parameters that affect it.

Once the evaluation parameters have been established, the dwellings of the interviewed students will be further examined as case studies in order to determine how design parameters such as circulation space, windows, building shape, and orientation affect the spatial quality parameters.

In the last part of the research, a visual quality evaluation model will be developed in the visual programming language Grasshopper, based on the identified visual quality parameters and the design elements that affect them. The evaluation model will be developed in an iterative process where it is repeatedly tested in the design process. Therefore, experimentation in the form of research by design will be applied as the research method for this part, to optimize both the designed alternatives of the student housing, but also the practical application of the evaluation model in the design process.

III. Results

3.1. Evaluation of Visual-spatial Quality in student dwellings

The purpose of this section is to investigate the parameters that express visual architectural quality through a literature review and interviews. The aim is to identify which parameters should be evaluated using a parametric model during the design process to improve the visual quality of student housing.

3.1.1. Visual Perception

Spatial experience and cognition of space are mainly based on visual perception. This occurs when light is reflected off objects and enters the retina of the observer, where the information is then interpreted by the brain. While the registration of reflected light in the retina occurs similarly for most individuals, the interpretation of the information is highly individual based on past experiences (Steemers & Steane, 2004).

The scope of vision is the first predetermining factor of visibility, where the object must be within the view of the observer, as the reflected light must be able to travel from the object directly to the retina of the observer. If any intermediate object obstructs this view, then the object behind it cannot be visually observed (see figure 1). This geometric nature of the scope of vision is why it is determined in the configuration process from early design stages as massing, walls, and floors will form obstructions in the view field (Bittermann & Ciftcioglu, 2008). Privacy works in the opposite way, as it is tested if the resident is within the scope of view to someone outdoors, while direct sunlight occurs when there are no obstructions between the window and the sun that is almost 150 million kilometers away from it.

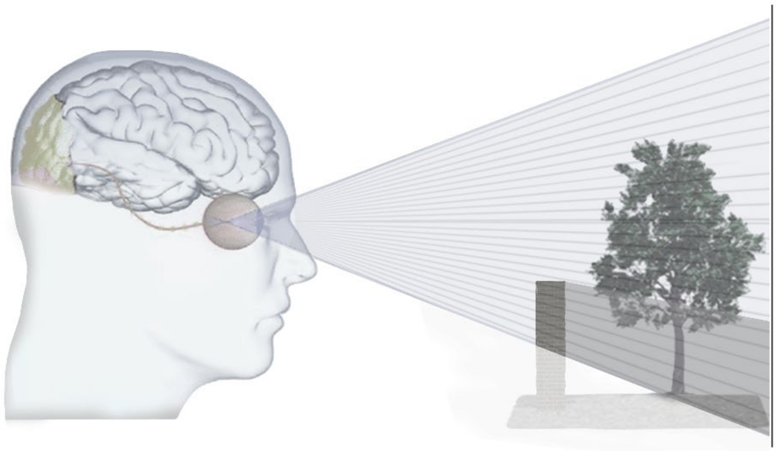

Figure 1. Visual Perception. An edited diagram from (Deng et al., 2019).

Therefore, testing daylight, view, and privacy is fundamentally determining the scope of vision, drawing vision rays in different directions and testing their intersections with surrounding objects. Designing a building determines the first obstructions in the direct environment, therefore establishing the scope of vision for the resident. Ultimately, users can decide to temporarily limit the scope of vision by elements within the dwelling such as curtains, while the obstructing elements outside the dwelling are not within the influence of the inhabitant.

3.1.2. Literature study Visual-Spatial Quality

Visual quality can be evaluated geometrically through intersections, but to analyze its quality it is essential to determine what parameters should be addressed. In this subsection, the quality of daylight, views, and privacy, and its possible evaluation parameters will be investigated through a literature review.

3.1.2.1. Daylight

Natural lighting has a significant impact on the happiness of people, particularly for young individuals under the age of 30 (Morales-Bravo & Navarrete-Hernandez, 2022). Cheung and Chung (2008) conducted a conjoint analysis to determine the factors that affect the daylit residential indoor environment and identified general brightness, desktop brightness, perceived glare, sunlight penetration, and user-friendliness of shading devices as important. Zanon et al. (2019) propose daylighting and glare as the main evaluation parameters for natural light, while also acknowledging the importance of view out and the availability of shading devices.

The minimum requirements for daylight have also been described in Dutch building regulations, where the evaluation of daylight is currently done according to the standard NEN-EN 17037. This standard recently replaced the previous standard NEN 2057. The key difference between these two standards is that the new EN 17037 normative introduces the assessment of view out and protection from glare (Mijzen, 2022). Therefore, in this paper, the NEN-EN 17037 and the additional guiding normative for the implementation in the Netherlands (NEN 4057) have been studied.

Standard EN 17037 is divided in 4 evaluation categories: daylight, view out (addressed in the next sub-section), exposure to sunlight and glare (Stichting Koninklijk Nederlands Normalisatie Instituut, 2018). While only daylight calculation is required by Dutch building regulations (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022), the other categories undeniably also contribute to improved visual-spatial quality and will be discussed as well.

Daylight as luminance distribution

The evaluation of daylight in terms of luminance distribution, in accordance with EN 17037, can be performed using two different calculation methods. The first method, the calculation of daylight factor, is relatively simple. It is based on an overcast sky, without considering the location or time of the year.

The second method, which is more detailed, evaluates daylight based on the calculation of illuminance level. Both methods state that the target illuminance of 300 lx should be achieved for 50% of the calculated area for at least half of the calculated hours throughout the year, while a minimum target illuminance of 100 lx should be attained for 95% of the calculated area. The second method, which calculates illuminance level, can provide more accurate results for rooms with optimal orientation that receive direct sunlight, but it is also more computationally intensive, requires more input, and takes more time (Stichting Koninklijk Nederlands Normalisatie Instituut, 2021).

Direct sunlight

Direct sunlight can positively affect both the mental and physical health of the resident as well as the perception of indoor space (Morales-Bravo & Navarrete-Hernandez, 2022). Its evaluation is often based on an analysis of obstructions between an assessment point and the sun position at certain time periods, expressing the results in sun hours that the analysis point receives direct sunlight.

NEN-EN 17037 evaluates exposure to direct sunlight based on the hours of sunlight per day in the period of February 1st to March 21st. The advised date of analysis is February 19th (Stichting Koninklijk Nederlands Normalisatie Instituut, 2021), which will also be used in this research. During this time, it is recommended that at least one room of the dwelling receives a minimum of 2 hours of sunlight per day, while for medium quality 3 hours are required and for high quality 4 hours of direct sunlight per day. Additionally, in the Netherlands, the direct sunlight hours count only for the hours when the sun altitude is at least 11 degrees. As such, on February 19th, the direct sun hours would be evaluated within the timeframe between 9:20 and 16:40. As more than 4 hours of direct sunlight can potentially be favorable, a further distinction in quality will be made for dwellings that receive direct sunlight more than 4 hours a day with a maximum being 7.33 hours on February 19th.

Glare

The presence of direct sunlight can also lead to the occurrence of glare, which can cause headaches and fatigue (Reinhold & Tint, 2009). The perception of glare is highly dependent on the position of the observer and their line of sight, and it should be assessed primarily in places where dwellers conduct activities such as reading, writing, or using display devices and cannot freely choose their position and view direction.

Since the risk of glare is always present as long as the space receives direct sunlight, completely eliminating any chance of glare is impossible. Instead, a dweller should be able to control solar shading that reduces the perceived glare while maintaining diffuse daylight. Also, in NEN-EN 17037, the prevention of glare is discussed through the choice of glazing and shading rather than the configuration of space and calculation of glare possibility (Stichting Koninklijk Nederlands Normalisatie Instituut, 2018).

Since the choice of shading and glazing can be made in later stages in design, its calculation in configurative process is premature. Therefore, the possibility of discomfort due to excessive sunlight will be evaluated as the percentage of hours when the upper useful daylight illuminance (3000 lx) is exceeded. While this is not an accurate evaluation of glare possibility, the simplicity of this calculation method can still provide useful information to compare different design options in the early design stages (Torres & Verso, 2015).

3.1.2.2. Views

The quality of the view certainly has a significant impact on the observed visual quality (Kim et al., 2022). However, our past experiences and individual preferences greatly affect our perception of the view, making objective evaluation very challenging (Bittermann & Ciftcioglu, 2008).

While the ultimate experience of the view is highly individual, view-affecting parameters have been studied before. Ko et al. (2022) have determined content, access, and clarity as significant aspects of view quality. Content refers to visual features that can be observed from the window such as nature, horizontal layers (ground, landscape, and sky), distant elements, and movement (people, nature, weather). Access is primarily related to the size of the visible area from the window, which could be measured with view angle and distance, while clarity addresses view-disturbing elements such as shading and glazing.

The quality of the view has also been addressed in the building standard EN 17037, specifying objective evaluation criteria being view angles, visibility of layers, and view distance, while also acknowledging subjective parameters such as visibility of people, greenery, and weather. The overall quality of the view is the lowest-scoring parameter from angle, distance, and layers (Stichting Koninklijk Nederlands Normalisatie Instituut, 2018).

View angle

The view angle, or width of the view out, is measured according to EN 17037 at the furthest point in the utilized area from the window, which determines the view quality of the whole room. The angle is measured between two lines from the point to each vertical edge of the window. If there are multiple openings with little distance between, the sum of the openings may be used. To achieve minimum quality, the angle should be larger than 14 degrees, while for medium and high quality it is 28 and 54 degrees, respectively (Stichting Koninklijk Nederlands Normalisatie Instituut, 2018).

View distance

The view distance in NEN-EN 17037 is calculated on a line perpendicular to the window surface, from the inside of the window, till the nearest obstacle outside. The division in minimum, medium, and high quality is, respectively, a distance of 6, 20, and 50 meters. (Stichting Koninklijk Nederlands Normalisatie Instituut, 2021).

View layers

According to EN 17037, the view layers of ground, landscape, and sky are evaluated based on what is visible from 75% of the dwelling. The calculation height is 1.2 meters above the floor level, and the evaluation is made in a 2D section, perpendicular to the opening. A minimum level of view is achieved when only the landscape layer is visible, medium view quality when one additional layer is visible, and high view quality, when all 3 layers are visible from 75% of the area (Stichting Koninklijk Nederlands Normalisatie Instituut, 2018).

View on nature

The view of nature has not been objectively quantified in EN 17037, but its impact has been acknowledged as a subjective factor. Additionally, the view of nature has been recognized by Ko et al.(2022) as a significant factor in improving visual quality. It is possible that the quality of visible greenery could be evaluated by analyzing the intersection of view lines between the dwelling and green areas, but this falls outside the scope of this paper.

3.1.2.3. Privacy

Privacy is a less-studied subject than daylight and view quality, and it has not been directly addressed in Dutch building regulations or standards. However, depending on culture and individual, privacy may often be valued higher than daylight and view to outdoors (Al-Kodmany, 2000; Rapoport, 1970; Veitch et al., 2013).

As TU Delft has students from different backgrounds and cultures, considering visual privacy in the evaluation of spatial quality is crucial. While the perception of privacy is rather subjective, existing research often addresses the quality of privacy through visual exposure, determining how exposed the area of dwelling is to external spaces such as other building façades or streets (Shach Pinsly et al., 2007; Zheng et al., 2021).

The evaluation of visual privacy with the help of computational methods has been attempted before. Hwang and Lee (2017) have expressed the value of privacy with visual refuge area, that is the area in a building that is not exposed to external observers. However, this evaluation of space considers it either exposed or not exposed, not examining the impact of the distance of the observer. The eye level of the observer has been set to 1.6 meters. The position of the external observer has been determined in a grid of points.

Shach Pinsly et al.(2007) have evaluated visual exposure through sightlines as a distance between viewpoints, proposing distance as the main evaluation criteria. The height of the viewpoints is 1.6 meters above the surface on which the observer is standing. A categorization is made into four different categories of sightline lengths, starting with distances under 10 meters, which are considered high visual exposure, while medium, low, and very low visual exposure are represented by values higher than 10, 25, and 50 meters respectively. The total visual exposure is measured based on the number of sightlines in each category. However, the visual exposure was measured on the external surface of the dwelling, consequently giving the same value of visual exposure to the whole dwelling.

Zheng et al.(2021) proposed a model for evaluating the privacy of residential spaces through the assessment of visual exposure. This model takes into account various factors such as the opening area of the observer and target buildings, the distance between the observer and target, and the direction of the observer's line of sight, in order to calculate the level of visual exposure. The study adopted the formula $V = 1/d^2$ from the work of (An et al., 2015) to estimate the effect of distance on visual exposure, with the total visual exposure represented as the sum of the reciprocals of the squared lengths from all sightlines. Additionally, the direction of the observer's line of sight is expressed in terms of the cosine values of the horizontal and vertical angles.

3.1.3. Results Interviews visual quality evaluation

To gain further insights into the perception of visual-spatial quality perception by students of TU Delft, a number of interviews have been conducted (Appendix A). The interview questions were structured in a way to determine if the evaluation parameters that have been identified through the literature review are recognized as important by the students.

Most of the evaluation parameters were considered meaningful by the students, but their relative importance varied greatly due to individual priorities regarding visual-spatial quality. The type of housing varied from studios to shared housing with 16 other people. All rooms had only openings on one façade, while their orientation and direct context were highly variable.

The situations in which the interviewees prioritized daylight, view, and privacy were similar: most preferred having privacy when sleeping and changing, while all desired daylight when studying.

The perception of daylight also varied per interviewee, as some prioritized direct sunlight over the illuminance of the room, while others stated the opposite. Also, half of the interviewees experienced glare very often, mostly ones with openings facing south.

Interviewees living higher up generally valued their views more. Having greenery in the view was expressed as important by all interviewees, and having a dynamic view of people was also a commonly stated desire. Seeing in the distance and having a wide view was also acknowledged to positively affect the perceived view quality by most interviewees. More varied preferences were observed concerning the visibility of the view layers as stated by EN 17037. Their relative difference in importance varied greatly, and often the importance of the landscape and ground layer was linked with the elements visible in the view.

The greatest difference in answers was recognized in the aspect of privacy, as 2 of the interviewees expressed it as not being important, 4 as important, and 2 as very important. The two interviewees that valued privacy the highest also lacked its quality most. Also comparing the influence on privacy from potential observers from the street and opposite buildings the answers varied greatly. The minimum distance for the observer to be far enough not to influence privacy ranged from 20 to 100 meters, with most answers in the range of 20-30 meters. While most interviewees require privacy only when sleeping and changing, interviewees 6 and 7 would prefer to be unseen most of the time. In the case of interviewees, 3 and 6 exact opposite preferences were stated. When studying, Interviewee 6 couldn’t focus if they felt exposed, while interviewee 3 favored visual exposure to the street to feel connected to society.

3.2. Design parameters that influence spatial quality

Having determined the evaluation parameters that should be addressed in the parametric model, the next step is to determine the architectural and context elements that are likely to influence the perceived visual quality of the dwelling. These identified elements are a required input for the evaluation model to conduct the assessment.

3.2.1. Architectural influence domains of obstructing elements

In the previous section discussed evaluation parameters are primarily affected by the scope of vision that is formed by its limiting obstructions. View distance is determined by the intersection of the view line with the nearest light obstructing element, while visual exposure is experienced when there are no obstructions between a potential observer and the evaluation point.

Obstructions that are within the control of the resident include curtains and furniture. Architect places obstructions such as floors, walls, and windows, while some obstructions may be contextual and cannot be influenced by any specific person.

To clarify the nature of different obstructions, they will be separated into four distinct domains (see figure 2). The first domain is ''unit residential'' which includes elements that can easily be influenced by the resident such as curtains, furniture or even properties of wall such as color. Unit architectural includes interior walls, windows and doors. These elements can be altered with minor impact on the building as a whole. The obstructions on site scale include the building itself as mass, but also greenery. Finally, the context domain includes all elements outside the site, such as surrounding buildings and natural elements.

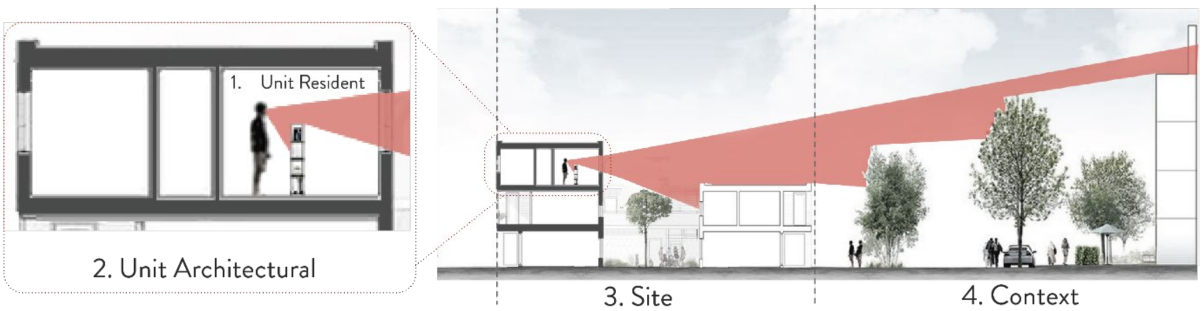

Figure 2. Visual obstruction influence scales. A combined diagram of images from ADHOC architectes (2017) and The Landscape Company (2021)

Ideally, the existing obstructions should be limited on the site scale and maximized on the unit residential scale, as this gives the resident the most control to determine a desirable level of the scope of view based on their preference for more privacy, view, or daylight.

3.2.2. Identifying possible visual obstructions on different scales

To determine what inputs must be considered in the evaluation and what type of data geometry can reference it, various elements have been identified based on the interviewed student dwellings. Images of the dwellings can be found in Appendix B.

3.2.2.1. Unit Residential

As shown by the interviews, residents generally desire a certain level of control over the amount of light they receive and the view of the outside from their dwelling, which can vary based on the time of day or year. To adjust for these changing conditions, residents can use curtains or rearrange their furniture to suit their preferences.

As a curtain can provide a simply adjustable obstruction, it is the most commonly used interior element to attain the desired result. From the interviewed students, all had curtains in their dwelling, and except for interviewees 2 and 3, everyone else had bought the curtains themselves, either because they were missing before or because the properties of the provided curtains were not satisfactory according to them. Interviewee 6 replaced metallic venetian blinds with lighter, more translucent curtains to maintain privacy while letting through the light. Interviewees 1 and 5 did the exact opposite and replaced more translucent curtains with ones that would block more light.

The different preferences of visual quality also show in the use of curtains by the interviewees. Interviewee 1 keeps the curtains closed on at least one of their windows during the day, and may close both windows if there is too much daylight. Interviewee 6 always keeps their curtains closed during the day to have more privacy and limit the view to the outside, which they find distracting. Interviewees 2, 3, 4, and 8 only closed their curtains partially when experiencing glare, while interviewees 5 and 7 never keep blinds closed during the day. During the night, most interviewees keep the curtains closed, however, interviewees 2 and 8 keep them partially open to get morning light when waking up and interviewee 4 occasionally keeps the curtains open for night view.

There are different types of curtains and in order to get the most control over daylight, view and privacy, a combination of two curtains can give more freedom to the resident. For example, a translucent curtain could be used when privacy and daylight is desired, while a blackout curtain is more suited when daylight is not desirable. From the interviewed students, only interviewee 8 had two curtains, while usually only the blackout curtain was used as it was faster to open and close.

The arrangement of furniture, such as placing a desk closer to a window for optimal study conditions and positioning a bed for maximum privacy, can be used to benefit from different distribution levels of daylight, views, and privacy within the dwelling. Everyone except for interviewee 1 had their bed away from the façade. Interviewee 1 was also the only one changing their layout seasonally, however, the bed always stayed in the same spot. Most interviewees preferred having their desk next to the window because of the daylight. Interviewee 4 had bought an additional shelf to visually divide the bed from the rest of the room, and the other furniture they bought was in white color to reflect more daylight into the room.

Other more permanent elements that can adjust the level of privacy and view include translucent films. From the studied cases, these were only present in the dwelling of interviewee 6, who had installed them to enhance the level of privacy.

Lastly, repainting the walls can also be used as a measure to reflect more light in the dwelling. While 5 out of 8 interviewees had repainted their walls, it was more because of their preference for different color or quality of the paint, rather than changing the light reflecting properties of their previous color. However, when asked if they would repaint it to a brighter color if the walls were dark, most answered positively.

3.2.2.2. Unit Architectural

Unit architectural domain elements include any elements that could be adapted in one single dwelling, while having little to no impact on other dwellings in the same building. An example of this is interior walls and windows.

The shape of the floor plan among the interviewed students varied significantly. Interviewee 1 and 3 had dwellings that were relatively wide (over 5 meters), while interviewees 2, 4, and 7 had rooms that were under 4 meters wide. This difference is also evident in the number of windows, as the wider rooms had two windows, while the narrower rooms had a single window that proportionally covered a larger portion of the façade.

Residential design projects often incorporate multiple types of dwellings, such as studios, shared apartments, and corner units, which have distinct characteristics. For instance, a corner unit may have openings on two different façades, allowing for increased visual quality. In the parametric evaluation model, these dwellings and their various design elements should be efficiently referenced so that the evaluation process does not take excessive time. Ideally, it is done as often as possible, therefore, time for linking the geometry to the model should be reduced to a minimum. As each dwelling will have one or more windows, for a project of over 250 student residential units, the basic window geometry should also be made within the grasshopper model so that any changes in window size, positioning, and addition of other dwellings can be studied effectively.

3.2.2.3. Building and site

One of the biggest differences between architecture unit and site scale is how the mass of all units impact the total composition and each unit individually. While changing a window size for a single unit makes all the difference for the particular unit for which it is changed, it has little if any impact on other units. However, on the site scale, introducing measures that will improve visual exposure for one unit, such as planting a tree, might block too much sun and view for a unit below it. Therefore, improving one or a few units might lead to decreased quality of other units. Building scale is also where the evaluation model is likely to provide the most useful information for the designer, as the design decisions and the various created alternatives can be compared with each other and expressed in visual quality parameters for each dwelling.

The design decisions made on this scale would include the orientation of the building and its façades, the composition of the massing, circulation access, and landscaping elements. Any light or view obstructing elements such as trees or walls should be linked to the grasshopper model as 3D geometry so that they can be used in the evaluation through intersection with view lines.

For the evaluation of privacy, any surfaces which are accessible to potential observers such as public areas, terraces, or galleries access that pass by the windows of residential units must also be linked to the model as surface geometry. This will enable the analysis of privacy from different observer locations and help to determine the perceived level of visual exposure.

3.2.2.4. Context

The context scale is the largest of the four scales and encompasses all elements that are outside the site or cannot be changed within the site. These elements cannot be modified by the architect or the residents, and their influence on the site is consistent, regardless of different design alternatives. However, future scenarios can be analyzed by changing context elements to see how each design alternative would respond to change.

The context scale includes surrounding buildings, greenery, and infrastructure elements that will be used to test intersection with view lines and daylight, as well as to determine additional observer locations for evaluating privacy. It also includes larger geographical information, such as climate data in the form of an EPW file and the true north rotation, which is consistent across all analyzed design options and referenced on the context scale.

3.3. Building computational evaluation model

In this subsection, the process of constructing the parametric evaluation model through experimentation will be discussed. The evaluation model was built using the visual programming plugin, Grasshopper, which is an extension for the 3D modeling software, Rhinoceros. While other software alternatives, such as Dynamo, a plugin for Revit, are available, Grasshopper was chosen due to a higher degree of familiarity with the software. Additionally, other plugins to Grasshopper, such as Honeybee and Ladybug, were used primarily for the analysis of daylight.

3.3.1. General considerations for scale and accuracy

The designed program for student dwelling will consist of approximately 250 units with an average floor area of around 25 square meters. In assessing parameters such as luminance distribution, which are calculated on a 0.5-meter grid, the total number of sensor points would amount to approximately 25,000. This calculation would entail a significant amount of computational effort and time. Such a parametric evaluation model would lose its ability to efficiently provide the designer with useful information, making it difficult to implement design changes and reevaluate their effect in a short time. Instead, the model would be characterized by extensive computational demands, which could likely mean that it would be used less frequently.

When constructing the evaluation model for different visual parameters, it was apparent that the analysis of a grid of 0.5 meters for the entire building would likely not be computationally feasible for most evaluation parameters. Therefore, the evaluation will be done on two scales: building and unit. The building scale evaluation will be conducted for a dwelling as a whole with one evaluation point representing the whole unit, while the unit scale will analyze one selected dwelling in detail and display its visual quality parameters in a grid of 0.5 meters within the dwelling, to see how the visual quality is distributed within the dwelling. Evaluating design alternatives on these two scales will also structure the design process by first achieving good visual quality for all dwellings on a site scale, and then trying to improve individual dwellings by tweaking the architectural unit scale parameters.

3.3.2. Preparing model for evaluation

To evaluate the design on various visual quality parameters, the geometrical input must be prepared by specifying different surfaces and their properties as well as the analysis points. Additionally other context information must be specified for accurate analysis of daylight.

Climate data has been imported as an EPW file (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2001) for the location of Amsterdam. While this data is not exactly precise for the design location in Delft, it is of sufficiently accurate for the purpose of the tool to compare various design alternatives in early stages. True north rotation of the location is -20.62 degrees.

In the further subsections, the process of creating analysis geometry from user input is described. The first step is to address the geometric input provided by the user. Subsequently, the methods for extracting floor, wall, ceiling, and window surfaces will be discussed. Thereafter, the process for creating a honeybee room for analyzing daylight will be presented, followed by creation of obstructing mesh geometry for intersection tests.

3.3.2.1. Geometric input

Geometric input and its data type has been specified in Appendix C. This data is specified by designer and is kept to minimum to be able to use the model with less input, saving time in the design process. Therefore, input such as windows is not specified as drawn 3D geometry, but rather a percentage of exterior face for each dwelling that is an opening.

When determining the geometric input for dwelling units, one of the key factors to consider is the type of input used. Initially, an approach of referencing building massing and then dividing it based on a grid was attempted. However, during the design process, it was concluded that student dwelling design through additive process is more clear and efficient. This process involves creating individual units as separate masses and then assembling them to form the building. This approach offers greater flexibility as units can be easily added or removed, and the total number of units can be easily tracked. To distinguish the exterior walls of the units, building massing input was specified in a way that allows for measuring the distance between the faces of the units and the massing geometry, thus enabling the estimation of the relative positioning of each unit face to the envelope.

In order to evaluate privacy, it is necessary to identify potential observer locations. This is accomplished by inputting surfaces and dividing them into a grid of points of a specified size. Each point represents a possible location from which an observer could look into the dwelling. The size of the grid chosen for the analysis will affect the computational demands of the analysis, with larger grid sizes resulting in less precise but less computationally intensive analysis. Therefore, when selecting the grid size, it is important to carefully consider the scale of the design project and balance the tradeoff between precision and computational demands.

3.3.2.2. Architectural surfaces from unit massing

The input for dwelling units is a 3D mass. To extract the walls, floors, and ceilings from this mass, the BREP geometry is deconstructed to retrieve its bounding faces. These faces are then separated into floors, walls, and ceilings based on their normal vector Z value.

To distinguish exterior walls from other walls, the center point distance of each wall to the building massing surfaces is measured. These surfaces represent the envelope of the building, and walls that are located next to them are exterior walls.

Windows for dwelling units are created by scaling the exterior wall surfaces with a factor in the range of 0 to 1, representing the proportion of the opening area to the exterior surface. When evaluating daylight, view, and privacy in dwelling units with multiple windows, it may be beneficial to test scenarios in which one of the windows is closed, such as a north-facing window adjacent to a gallery access. This can be accomplished by removing that window from the calculation and running the evaluation again.

To analyze visual quality, specific evaluation points must be determined. For building-scale analysis, the center point of the dwelling is used, except for direct sunlight analysis which is done at the center of the window surface. For unit-scale analysis, the unit is divided into a grid of points using the Ladybug generate point grid component.

3.3.2.3. Honeybee room creation

Before evaluating daylight illuminance level on unit scale with Honeybee annual daylight component, room model must be built where room surfaces and their optical properties must be specified. To do this TU Delft TOI-Pedia tutorial was followed. (TU Delft, 2022). The material optical property values were obtained from the same tutorial as it also aligns with the reflectance values proposed by NEN 4057.

The room surfaces such as floors, exterior surfaces, windows, and ceilings were specified using the previously extracted surfaces from the unit mass geometry. This simplified the evaluation process, reducing the time and user input required.

3.3.2.4. Creating obstruction meshes for intersection testing

Contextual elements such as other buildings and trees can affect view lines and daylight, influencing the parameters of visual quality being evaluated. To assess their impact, these elements will be linked to the model as meshes, which will later be used to check for intersection with view line curves. Mesh-type geometry is used for this purpose as it is computationally less intensive than BREP geometry.

On the unit scale, the initial obstructing geometry consists of the floors, walls, and ceilings of the unit. These surfaces are obtained from the honeybee room model, where the windows are removed, leaving only view-obstructing geometry meshes.

3.3.3. Assessing separate evaluation parameters

In this subsection the evaluation of different visual quality parameters on building and unit scale will be discussed. For each evaluated parameter the made decisions in the process of building the model have been described.

3.3.3.1. Building scale

Daylight as direct sunlight

The analysis of daylight on a building scale is limited to direct sunlight only. For each dwelling, the exterior faces are evaluated at their center point on February 19th, within the time frame of 9:20-16:40, with 3 time intervals per hour, for a total of 22 analyzed time frames. Weather information and true North rotation are specified from previously discussed input.

The analysis is conducted using the Ladybug direct sun hours component and is done separately for each of the 22 time intervals. This is crucial as the hours that the East and West façades receive sunlight are different, while for a corner dwelling with South and West façades, the hours would partially overlap. This would lead to an inaccurate total if the values were simply added. Instead, each list of results only includes information over a single time frame for each dwelling. For instance, if there are two surfaces, the list has two values and each has a result of either 0 or 0.33, as the analyzed time frame is 20 minutes or 0.33 hours. The list of results is then sorted in ascending order and the highest result represents the dwelling as a whole. In case the dwelling had at least one opening that received sunlight at the particular time frame the result is 0.33, and if not, then the result is 0. All single timeframe values are added together for each dwelling with the maximum result being 7.33 in case during all 22 time frames at least one opening received sunlight.

View angle

Evaluating the view angle according to EN 17037 gives one value for the whole dwelling based on the furthest point in the utilized area. However, as the quality of the view is likely not equally important throughout the room, in this paper it will be assessed in a grid of points throughout the dwelling similarly to illuminance evaluation. Each point will receive its own score in the range of 0 to 180 degrees. Additionally, as having multiple windows can provide added view width quality, even if the windows are not close to each other, the sum of all angles from each point will be used as the overall view angle for the analyzed point.

To calculate the view angle, two vectors are drawn from the analysis point to the vertical edges of the windows at the same Z coordinates as the evaluation point. The angle between these two vectors is measured. In the dwellings where multiple windows are present, the measurement is repeated for each window, and the outcome is the sum of the angles. Because the angle measurement between two vectors does not demand a significant amount of computational power, the angles can be calculated for all the dwellings in a grid of 0.5 meters. On the building scale, the outcome for the dwellings is represented as the average view angle from all points.

View distance

The EN 17037 standard measures view distance only in a vector perpendicular to the window plane. However, it can be argued that the view to the right and left also has an impact on the overall quality of the view. In this paper, angled view distance will be considered in addition to the perpendicular vector. Additionally, the quality of the view will be evaluated in an absolute manner, rather than being divided into minimum, medium, and high quality views based on the specified values in EN 17037.

On a building scale, the view distance will be measured from the center point of a room, projected 1.2 meters above the floor surface. From this point, a line is drawn to the window center point projection at the same height. Three additional lines are then polarly arrayed to each side of the center point so that the outermost lines reach the edges of the window. These lines are extended by 300 meters, starting from the window and continuing outside, with the first part of the line up to the window being trimmed. This allows for testing of the lines against all possible intersections from surrounding objects, while not testing it against the dwelling itself. Therefore in this calculation in case the line does not intersect any objects, the maximum possible score in view distance is 300 meters. If a line has any intersecting points with surrounding objects, the distance to the closest intersection point is the view distance for that line. The distance of 300 meters has been specified based on the given context as the Rhino 3D model surroundings have not been modeled past this point. However, in reality the view could reach further and be therefore potentially of even higher value.

When calculating the total quality for the window from all seven lines, the middle line is still likely to be perceived as the most important. Therefore, the total value for the window is calculated as the middle line distance plus the average of all other lines, and the sum is then divided by two. In case multiple windows are present, the result for the dwelling is the highest scoring window.

View layers

In this study, the visibility of various view layers on a building scale will be evaluated from the perspective of the center point of each dwelling. The center point is selected for ease of reference and is projected at a height of 1.2 meters above the floor surface. This approach is taken instead of estimating visibility from a point that would represent a minimum of 75% of the dwelling, as specified in EN 17037. Additionally, the view will not be assed in a 2D section, based on the same reasoning as for view distance, that more layers might be visible diagonally.

Similar to method for calculating view distance, view lines will be arranged to reach the edges of the window and then extended by 300 meters and trimmed by the length of the segment inside the building. However, in this case, the horizontal lines will also be polarly arrayed in vertical direction, dividing the window area into 3 horizontal lines and 5 vertical lines. This division was chosen based on experimentation, with the aim of achieving sufficiently precise results while also minimizing computational demands.

The lines will then be divided into two groups: one group consisting of lines that decline in angle towards the ground, and the other group consisting of lines that incline towards the sky. These lines will be tested for intersection with context objects, and if at least one line from each group does not have any intersections, the layer is considered visible from the dwelling. This applies to both ground and sky layers. The landscape layer is considered visible as long as the window sill is below 1.2 meters. In the case multiple windows are present for the analyzed dwelling, the layer is considered visible if it can be seen from at least one window. The total value for each dwelling for view layers ranges from 0 to 3, based on the number of layers that are visible.

Privacy

On the building scale, privacy is evaluated through assessing visual exposure similarly to the model of Zheng et al.(2021). Each window center point is projected at a height of 1,6 meters above the floor as the target point or points in case there are multiple windows for each dwelling. The observer points are all other target points (windows of other dwellings) as well as points retrieved from specified surfaces of possible observers, where their location is assumed in grid of points of 4 meters. While the use of a 4 meter grid in experimentation may not yield precise results, decreasing the grid size would require a significant amount of computational power and time, hindering the performance and practicality of the model in the design process.

To calculate the visual exposure, sight lines are made between the target point of each window to all possible observer points. To efficiently test sightline intersections with obstructions such as trees or buildings, the angle between the sightline and the normal vector of the window surface is first measured. If the angle exceeds 89 degrees, the sightline is discarded as it would not offer a view of the window, effectively reducing the number of sightlines that require intersection testing and lowering the computational power required.

Consequently, the sightlines are tested for intersection with surrounding objects. As the sightline is direct view from the observer point to the window, any intersections in between would mean that the view is interrupted. Therefore, all sightlines that intersect with any obstructing geometry are discarded.

The remaining sightlines can be perceived as valid and are used in the calculation of visual exposure for the target point. Each target point has a list of valid sightlines, where their visual exposure value is calculated with the following formula:

$$\text{Visual exposure} = \sum_{j}^{n} \frac{A_i}{d_{ij}^2} \times \cos\alpha_{ij} \times \cos\beta_{ij}$$

First, the area of the window opening (A) is divided by the square of the length of the view line (d). This quotient is then multiplied by the cosine of the horizontal angle (α), as determined prior to testing for intersections, and by the cosine of the vertical angle (β) between the sightline vector and its horizontal projection. In case the view is directly perpendicular to the window surface, both the cosine values are 1 as both the horizontal and vertical angles are 0 degrees. The visual exposure for the window is determined by summing the results of all evaluated sightlines. In dwellings where multiple windows are present, the visual exposure value for the dwelling is obtained by summing the visual exposure values for all its windows.

3.3.3.2. Unit scale

Daylight as luminance distribution

At the unit scale, the level of illuminance over a grid of 0.5 meters throughout the room will be assessed. This evaluation is performed using the Honeybee Annual daylight analysis component, which evaluates daylight autonomy as a percentage of occupied hours during which the illuminance is above 300 lux.

The choice to evaluate illuminance over daylight factor was made to account for optimal room orientation towards the South or West. The calculation is executed for an annual situation at high-detail level settings.

Daylight overexposure

This evaluation is performed to analyze the likelihood of excessive sunlight exposure within the dwelling. It is also conducted using the Honeybee annual daylight analysis component, similar to daylight autonomy, but in this case, the results for upper useful daylight illuminance are used, which indicate the percentage of hours when the illuminance exceeds 3000 lux.

View angle

The evaluation of view angle on a building scale is performed separately for each dwelling on a grid of 0,5 meters, and expressed as an average value across all evaluation points. At the unit scale, the results are extracted from the building scale analysis as a branch of data for the analyzed unit. Instead of displaying the average value of all points within the dwelling, the results for each grid square are presented separately to demonstrate the variation in view angle throughout the room.

View distance

On the unit scale the view distance is assessed in a very similar way to the building scale. However, in this case the analysis points are extracted as the grid points from the dwelling floor surface in a grid of 0,5 meters, projected 1,2 meters above the floor. The 7 lines are then drawn from each point to each window, and the results for each point are calculated in the same manner as on the building scale. Ultimately each grid point receives a value that is based on the highest scoring window visible from that point.

View layers

The procedure for analyzing view layers on a unit scale is consistent with that used for the building scale, with the distinction that it is performed from each of the grid points rather than from the central point of the dwelling. The horizontal and vertical division of lines that are tested for intersection with context objects remains unchanged. This approach allows for a more detailed analysis of view layers within the unit, providing a better understanding of the visibility of different view layers from within the dwelling.

Privacy

The privacy in unit scale is evaluated in a similar manner to building scale, only in this case the target points are the grid point of the dwelling, rather than the window center point projection. The grid points are projected 1,6 meters above the floor surface area in a grid of 0,5 meters. The observer points to which the sightlines will be drawn remain the same. Additionally, when the intersection is tested, the mesh of the room model from constructed Honeybee model is used as it represents the sightline obstructions in form of walls (without windows), ceilings and floors of the analyzed dwelling. The remaining sightlines are then again used in the calculation according to the same formula as for visual exposure calculation on the building scale.

3.3.4. Uniform comparison of evaluated parameters between design alternatives

All evaluated parameters have their own range of values and units of measurement. Therefore, it is challenging to compare different design options as the benefits of a 20 degree wider angle cannot be directly compared to the disadvantages of a 2 unit increase in visual exposure. To make the results more consistent, each parameter will be specified as a value between 0 and 1 based on the maximum and minimum specified values. For example, in the case of direct sunlight, the maximum possible value is 7.33 hours, and the minimum is 0. If a dwelling receives 7.33 hours of sunlight, its direct sunlight result is 1. So when calculating the parameter value for each evaluated point, the result is divided by the maximum value of that parameter, resulting in a value between 0 and 1. The maximum value has been selected on the basis of experimentation process in the development of the parametric model. The maximum and minimum values per evaluated parameter are illustrated in table 1. The selection of the maximum value has a direct impact on the distribution of data within the range of 0 to 1. Specifically, a higher maximum value will result in relatively smaller differences between the evaluation points and a more compressed distribution of values within the range.

Table 1. Visual obstruction influence scales

Parameter	Unit	Minimum value	Maximum value
Unit_Daylight_Illuminance level	Percentage of annual hours	0	100
Unit_Daylight_Overexposure	Percentage of annual hours	0	100
Unit_View_Angle	Degrees	0	180
Unit_View_Distance	Meters	0	300
Unit_View_Layers	Number	0	3
Unit_Privacy	Number	0	4
Building_Daylight_Direct Sunhours	Hours	0	7,33
Building_View_Angle	Degrees	0	180
Building_View_Distance	Meters	0	300
Building_View_Layers	Number	0	3
Building_Privacy	Number	0	4

When evaluating privacy through visual exposure, it can be challenging to establish an upper limit as an observer could potentially walk right up to a window and look inside from a very close distance. Therefore, based on the evaluation formula discussed in the privacy evaluation subsection, where the window area is divided by the distance squared, the calculated value of visual exposure could result in a very large number. This could lead to polar extremes of apartments with incredibly high visual exposure, compared to which others would have practically none. To avoid this, an upper limit for visual exposure will be set at 4, which represents a window of 4 square meters with an observer standing 1 meter away and able to look directly inside. This level of visual exposure is comparable to a scenario where a gallery access is located directly next to the window. This is arguably the worst case scenario for privacy of a dwelling.

In the assessment of privacy through visual exposure, an increased value corresponds to a decrease in the level of privacy. To ensure consistency with other visual quality evaluation parameters, an inverse value is used such that a higher value corresponds to an improved evaluated parameter. Therefore, if the visual exposure value is 4, the evaluated privacy parameter is 0. A similar approach is applied to the daylight overexposure parameter, where a value of 1 indicates that the evaluated point never receives illuminance higher than 3000 lux.

The individual evaluation parameters are combined into a composite value for aspects of daylight, view, and privacy, as the mean value between all sub-parameters. These values are subsequently integrated into an overall visual quality value for the analyzed design alternative on both unit and building scales.

3.3.5. Graphic display of visual quality data

The evaluation of various design alternatives should be presented as clear visual data, to facilitate informed decision-making and support improvements in the design process. One commonly used method for grid point evaluation is the use of heat maps, where each evaluated square is assigned a color based on the achieved value. This representation effectively conveys the distribution of quality throughout the analyzed area. In this research, heat maps were utilized to compare three different design alternatives on a building scale. A selected dwelling from option A was then further investigated in unit scale analysis to examine quality division within the apartment. For color gradient grasshopper preset was used with red representing the minimum value of 0 and blue representing the maximum value of 1. The results of these analyses can be found in Appendix D.

While heat maps provide a comprehensive overview of the data, it can be difficult to distinguish small differences due to the limitations of the color spectrum. To address this issue, the exact value represented by the color is displayed at the center of the evaluated area, providing more precise data for the designer.

To support greater flexibility in the design process, a value dropdown menu has been created to allow for a quick selection and representation of different data sets to the designer. The user can switch between data displays on the building scale or unit scale, as well as view overall visual quality results or examine results for specific aspects of daylight, view or privacy on the selected scale. Additionally, for more precise information, individual evaluation parameters can be selected as discussed in section 3.3.3. The data presented in this selection represents only the individual parameter, thereby providing greater clarity by displaying the evaluation on its specific values (see Table 1), rather than providing a value in the range of 0 to 1.

The evaluation of privacy requires not only an understanding of the visual exposure level of a dwelling, but also knowledge of which observer points have the greatest impact on visual exposure across all analysis target points (see figure 3). This information is valuable to the designer as it can inform the placement of visual obstructions, such as trees or balconies, to enhance the privacy quality of certain apartments that have lower privacy quality. The display of observer point influence is available on both building scale, representing the observer point influence on all dwellings, and on unit scale, representing the impact within the selected dwelling.

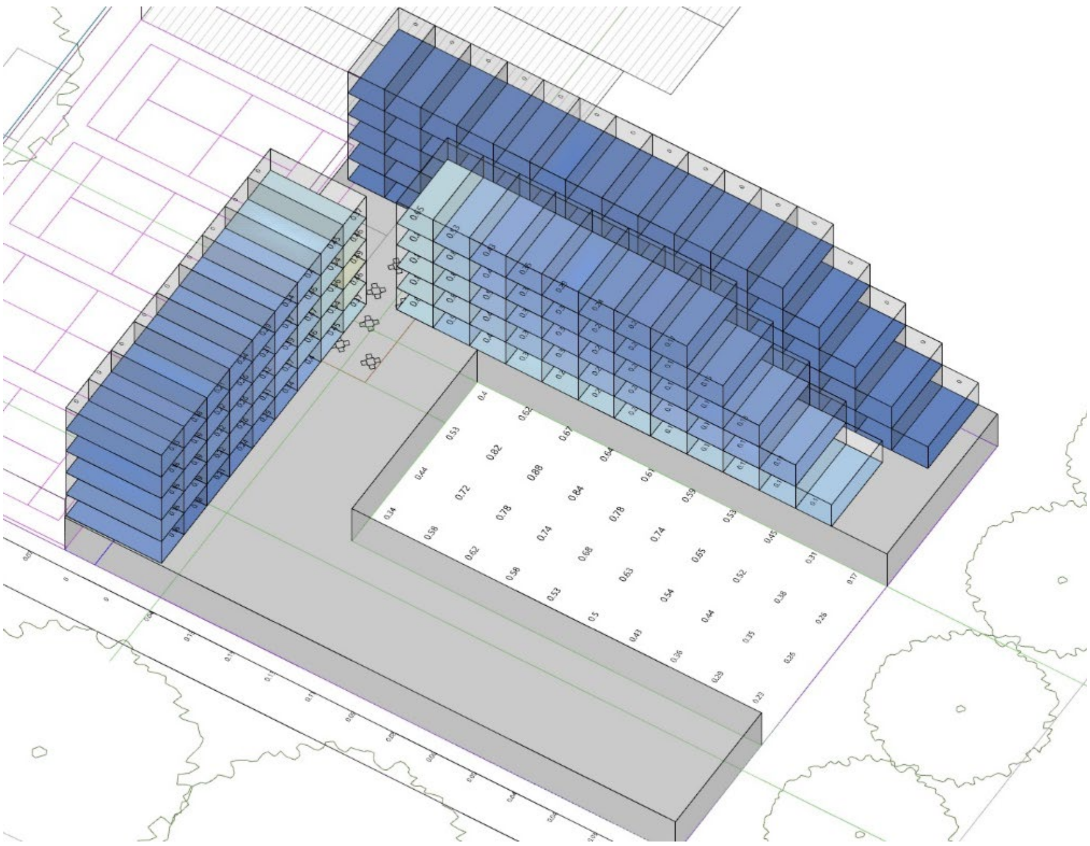

Figure 3. Privacy observer point impact building scale

IV. DISCUSSION

In the early stages of design, the visual quality of student dwellings can be effectively addressed by utilizing a parametric evaluation model. This model evaluates the 3D design geometry and provides clear visual data, in the form of heatmaps and number tags, which highlight areas where improvements are needed. The model can be used in an iterative process, structurally informing design decisions based on the evaluated parameters of daylight illuminance, overexposure of daylight, direct sunlight, view angle, view distance, view layers, and privacy. These parameters can be viewed as overall visual quality as well as individually for more detailed information.

The importance of visual quality factors such as daylight, outdoor views, and privacy for the well-being of students is well-established. However, they are not always explicitly addressed in the design process. The evaluation model provides explicit data on these parameters, but it cannot predict how the dwelling will be perceived in terms of visual quality, as perception varies from person to person.

To conduct the visual quality analysis, the model requires contextual input such as location and true north rotation, as well as geometrical information such as the 3D mass of the dwelling, view-obstructing elements, façade opening ratio, and surfaces of possible observers for evaluating privacy. The geometrical input can be either part of the context, which will stay the same between different design alternatives, or elements placed by the designer on the site, which will change in different design variations. Additionally, furniture elements within the residential unit will also affect visual quality parameters.

To make the use of the parametric evaluation model in the design process more practical, the relationship between the accuracy of the results and the required computational time of the evaluation has been optimized by conducting the analysis on two scales: building and unit. The former evaluates the dwelling quality as a whole, while the latter examines the distribution of spatial quality within a selected dwelling. This division was based on the designed program size of around 250 student dwellings. However, for the use of the parametric model on different projects, further optimization is likely required. Furthermore, the results on the building scale are not a translation from the unit scale, as the evaluated parameters and their methods are slightly different.

The evaluated parameters of visual quality and their perception, in reality, are also affected by other aspects not addressed in this research, such as thermal comfort, acoustic quality, air quality, and the presence of shading devices. Additionally, the proportional importance between the evaluated parameters is not addressed in this research.

While the constructed parametric model cannot be seen as a completely objective evaluation tool for all projects, it demonstrates that visual quality in residential architecture can be addressed more explicitly by geometrical testing and providing visual data to guide design decisions. Although interviews provided useful insights into student perception of visual quality, further research is needed to address the results in different age groups, cultures, and geographical locations.

V. CONCLUSIONS

This research aimed to answer the question ‘’How the parametric performance evaluation model of visual-spatial quality can enable more informed decision-making in the early stages of design for student dwellings?’’ To do this, visual quality parameters were first identified through a literature review and interviews with students. Design elements that impact visual quality were then identified and categorized into four different domains of influence. Finally, a parametric evaluation model was developed through experimentation, using the design elements as input to analyze the identified parameters.

Visual quality factors, such as daylight, outdoor views, and privacy, are important for the well-being of students but are not always explicitly addressed in the design process. The research found that the parametric evaluation model can address this by evaluating parameters such as daylight illuminance, view angle, and privacy, providing clear visual data in the form of heatmaps and number tags to highlight areas that need improvement. The model requires contextual and geometrical input and can be used iteratively to inform design decisions and compare different design alternatives. Additionally, the model has been optimized for practical use by conducting analysis on both building and unit scales.

However, the parametric evaluation model cannot predict how the dwelling will be perceived by different individuals. Additionally, the evaluated parameters of visual quality are affected by other factors such as thermal comfort, acoustic quality, air quality, and the presence of shading devices, which were not addressed in this research.

Nevertheless, this study has demonstrated the potential of using computational models in evaluating visual quality in residential architecture. To further investigate visual quality in dwellings, it would be necessary to research additional factors such as views of greenery and people, as well as the influence of furniture on visual quality.

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APPENDIX A: INTERVIEW RESULTS

0. Room and Interviewee information

R1: The interview took place on 10th December 2022 13:30-15:00. It was a cloudy day with moments of rain. Last semester in Bachelor of Architecture. Lives in a shared dwelling with 9 other roommates. The room is on the ground floor in city center facing east. The direct surroundings is a street and canal (gracht).

R2: The interview took place on 13th December 2022 11:00-12:00. It was a sunny day with direct sun shining in the room.. Graduate Industrial Design in Poland. Shares the apartment with 2 other people. The room is facing south and is located on the 13th floor in the South of Delft (Voorhof)

R3: The interview took place on 13th December 2022 13:00-14:15. It was partially cloudy at this point of the day. TU Delft Masters student in Urbanism living in a studio on Campus. The room is on the first floor facing west. Direct surrounding is a street, another residential building, small parking lot and green space.

R4: The interview took place on 13th December 2022 14:30-15:30. At this point of the day it was cloudy. TU Delft Masters student in Architecture living in a studio on Campus. The room is on the 3rd floor facing south towards InHolland education building cafeteria which is about 20 meters from the window 3 floors lower.

R5: The interview took place on 15th December 2022 11:00-12:00. It was a sunny day with direct sun in the dwelling. Recent graduate TU Delft Masters civil engineering. Living in a student studio near the city center to the east of Delft. The room is facing south and is situated on the ground floor. The direct surroundings are a green collective backyard.

R6: The interview took place on 20th December 2022 9:30-10:30. It was a cloudy and rainy day. TU Delft Bachelor Student Mechanical engineering. Shares house with 16 other roommates West from Delft center (Westkwartier). The room is on the first floor, facing North. The direct surroundings are yard space with some small trees in it that is shared with other houses in the housing complex. Currently, construction containers are placed there.

R7: The interview took place on 21st December 9:30-10:30. This time of the day was sunny. Currently in the graduation phase of Masters in Architecture. Lives in a shared dwelling with one other roommate in campus of TU Delft. The room is on the 9th Floor facing North. Direct surroundings are lower residential buildings (4 floors).

R8: The interview took place on 21st December 12:00-13:00. This time of the day was cloudy. Masters in Aerospace engineering student at TU Delft. Lives in a shared dwelling with 13 other people east of campus. The room is on the 4th floor facing South. Direct surroundings is a large water pond, Highway A13 and some green strip in between.

1. General questions visual- spatial quality

1.1. Comparing the qualities of daylight, view and privacy, which one is lacking the most and why?

R1: Privacy is the worst, then view, then daylight. Mostly exposure to buildings on the other side of the street affect feeling of privacy

R2: Daylight, view, and privacy are all great. I suffer the most from noise from neighbours. Sometimes I can hear them 6 floors below. Also, the cold air coming from poorly insulated windows causes a lot of discomfort.

R3: Ranking them from worst to best it would be view, daylight and then privacy. For view I would like to have a more dynamic view. Also daylight could be better- more direct sunlight and seeing sunset would be nice.

R4: Ranking them in order from worst t best- daylight, privacy, and then view. I don’t really care about the view that much and privacy is sufficient. Daylight really could be better especially in the kitchen area.

R5: Ranking them from worst to best- privacy, daylight, view. Daylight is sufficient when its sunny. The backyard is collective, but there are people walking by all the time, that is why privacy could be better.

R6: Ranking them from worst to best- privacy, view, daylight. The student housing facing my room makes me feel quite observed and also blocks the view. Daylight is sufficient, because there are large windows.

R7: Daylight could be better, because of the orientation there is almost no direct sunlight. Both view and privacy are excellent.

R8: All are great, but from the mentioned 3 views could be better. Currently, there is a construction site nearby which I do not like. I get a lot of sunlight in the room.

1.2. In which situations (sleeping, studying…) do you prioritize daylight, view or privacy? Why?

R1: While studying or reading daylight is the most important. When sleeping then noise from the street and from the roommates is the most bothering. During breakfast or when drinking tea, I like to sit next to the window and look outside.

R2: While studying daylight is important, but I like to take breaks and look outside in the distance. I never bother about privacy. During the night I leave the curtains partially open so that I would wake up with light shining in my room.

R3: I would really like to have more natural light when cooking, which I don’t get right now. When studying I really like daylight and the view to outside, I also like to be seen from the street when studying as it makes me feel like I am part of society. However, When I’m in my bed I want more privacy, even if I am not sleeping.

R4: I don’t really care about the view that much. Privacy I have preferably all the time, no matter what I am doing. Daylight I also like all the time, but especially when studying.

R5: When changing and sleeping I really need privacy, so I either close the curtains or go to the bathroom to change. For most of the other activities I like to have a lot of daylight and view.

R6: I really like to have my privacy all the time. Especially when changing or sleeping, but also when studying as I feel that I am getting distracted if other people could see me. That is also why I don’t like to have a view when studying, as I get easily distracted. Daylight is nice all the time.

R7: I like to have daylight when I wake up and when studying. I don’t really think about the view or privacy that much.

R8: The more daylight the better. Sometimes when I am waking up a little early I like to leave the curtains open so that I would wake up with the sun on my face. When studying I like to loo outside in distance and think.

2. Daylight

2.1 How do you experience the quality of daylight in your dwelling?

R1 Daylight is sufficient, but I would prefer to have some evening light. At least I get the sunset reflected from the opposite building.

R2 There really is a lot of daylight. I cannot complain.

R3 I feel like I have a lot of daylight as the windows are quite big, but it would be really nice to have more direct sunlight. Especially during the sunset.

R4 There is not enough daylight, especially in the back of the room. I would like to have another window in the back.

R5 It is enough, but it could be better. During cloudy days it feels quite dark.

R6 Daylight is good enough, but more would also be nice.

R7 I would give it a 6 out of 10. I really would want some direct sunlight.

R8 It is very good, I am really happy.

2.2 Is it more important to get a few hours of direct daylight per day throughout the year, or have a bright illuminated space (general brightness or direct sunlight)?

R1: Direct sunlight is more important because it warms up the room and makes you feel like you are outside. Since I recently had a concussion sometimes I feel like there is too much light and it makes me uncomfortable.

R2: Both are very important to me. I cannot prioritize one over the other.

R3: Very close to each other, but general brightness is more important.

R4: Definitely general brightness is more important. I do not care for direct sunlight.

R5: General brightness is more important.

R6: General brightness is more important. I don’t like direct sunlight, because it can make the room very hot, but if that would not be the case, then also direct sunlight would be very nice.

R7: General brightness is more important, but also direct sunlight would be really nice.

R8: Direct sunlight is more important.

2.3 Have you ever suffered from visual discomfort due to glare, if yes, what do you do?

R1: No, I have never experienced glare in this house.

R2: Yes, I get glare very often. I usually partially close the curtains to block the window next to the desk, but I still want to get daylight.

R3: Sometimes very rarely when I study in the late afternoon. I usually close the curtain, which lets through dimmed light.

R4: Sometimes I do. I either change my position or location in the room or close the curtain halfway. First I would try to change the position.

R5: Yes, I have it all the time, in fact right now as well. About 2 hours every day when it’s sunny. I usually just put on a cap, because closing the curtains takes too much time.

R6: Yes, I have it quite often. Mostly reflected from the white panels of the opposite building. I then just close the blinds.

R7: No, I have never had glare.

R8: Yes, I have a fair amount of glare. Especially when studying as my desk is next to the window. I usually just partly close the curtains.

3. View to outside

3.1 How do you experience the view quality outside your dwelling?

R1: It is all right, but it could be more interesting.

R2: The view is very nice as you can see far and quite wide. Also, the surrounding buildings are not really in the way that much.

R3: The surroundings are a little boring, I would really like to see some more dynamic views like a café. But then it might be quite loud and that I wouldn't like as well.

R4: It could be better. There could be more things happening, for example, if I could see some traffic of people going through the campus that would be nice to wonder where are they going.

R5: Except for the corona test center on the other side of the street, the view is very nice. There is a lot of green and since I am on the ground floor it feels like I have my own garden

R6: Really depends on the season. In summer it is very beautiful as the trees are blossoming and they block the view to the opposite building, so then I would give my view 8,5. In winter that is not the case and I would give it a 5.

R7: I really like my view! You can see all the way to the Hague and the whole campus.

R8: The view is very nice! You can see the pond and a lot of greenery. It used to be better before the construction started.

3.2 What is a good view for you? Is it about greenery, seeing in the distance, seeing certain landscape elements, or something else?

R1: Greenery is very important, but also seeing different people and different functions of buildings. Seeing in distance and wide angle of view is also very nice. Would be also nice if I could see the old church, but its not that important.

R2: Yes, greenery is important. Also the distance and wide angles. I really like that I can see the skyline of Rotterdam. Also, it is nice that I can see Lidl as I know when it's crowded and when I should go to do my groceries. Seeing the train is nice as well and even nicer that you cannot hear it.

R3: Greenery is important, but not if it is designed green- only when it is more natural. Also, people using it would be better. Seeing in the distance is nice as that brings more variety to the view. Also a more dynamic view would be very nice.

R4: Yes, greenery is important, but only when you feel like there could be something living there. So not grass, but rather trees and bushes. Also if at least some part of your view is far-reaching that would be very nice.

R5: Seeing green is the most important. Seeing in the distance is good, but not a priority.

R6: Green is important. My dream house would be in a forest surrounded by trees. But also seeing far in distance is nice.

R7: Yes, I prefer greenery over the cityscape. Seeing in the distance is also important and the further you can see the better. I like that I can see the skyline of the Hague.

R8: Greenery is important, but if it blocks the view in distance, that's not great, there should be a balance of distant view and greenery within the view.

3.3 Is the angle width of your view important (how wide is your view)?

R1: Yes, I really like that the view is wide. I also think it's important to have a wide view from the whole room, not just near the window.

R2: It's nice to have a wide view, but it would also be all right to have a more narrow view. It's really more about what you see than the size of the view.

R3: Yes, view angle is important, because a wider view means seeing more things, meaning that the view is more diverse, which is what I find important.

R4: Angle of the view is important, but I would not want a wider view if that means that I have to sacrifice my privacy.

R5: R5: Yes, the angle of the view is very important! That is why I chose this room over the newer-built studios that are deep and narrow.

R6: Angle of the view is very important. I love that the window is as wide as the wall. I think that the width of the view is important for the whole room, but as long as at least part of it is wide it's fine.

R7: Angle of the view is important. That is why I really like that my windows are so wide.

R8: Wide view is nice. Ideally, I would have a wide view from my whole room, but as long as my study and chill area have a wide view it's great.

3.4 Is it important that you can see the ground, landscape/building layer, and skies? Which one of these is the most important to you?

R1: The ground is the most interesting. The sky is not very important. Mostly I like to see people walking and doing things. The landscape layer is also nice to see.

R2: Landscape is the most important, then ground and then sky.

R3: Sky is the most important, then landscape, and then ground. But they all come very close.

R4: Ground is the most important because there is the most movement, then sky because of the weather context and then landscape.

R5: I really like to see all of them. The sky is the most important to me, then the landscape, and then the ground. Sky and landscape come close in how important they are.

R6: It's not very important for me to see the ground, the landscape layer really depends on what you see. In my case, I don't care for it because I am facing another building, but nature would be nice. The sky is the most important because I get information about the weather. Also, it never affects your privacy or distracts you.

R7: All layers are important. Most important is the sky, the ground then the landscape.

R8: It's important for me to see all 3. The ground is the most important, then the landscape than the sky. But it really depends on what you see. If its nature, then it's nice.

3.5 Doing what activities do you value the quality of the view?

R1: Mostly when I am eating breakfast or drinking tea next to the window.

R2: During small breaks when I study and when I talk on the phone. In the morning when I drink my coffee. Generally, whenever I am doing something that does not require visual focus.

R3: When there is direct sunlight. I really like the combination of the two.

R4: Sometimes when I study or eat breakfast.

R5: Whenever I take a break. In the summer when I eat breakfast.

R6: When I am doing some hobby things. Just as long as it doesn't distract me when I am studying.

R7: During summer I like to sit on the balcony and eat. Mostly when I sit outside. Otherwise really only when I show it to other people who visit me.

R8: When studying I like to look outside and think. Also when I am sitting on the couch.

4. Privacy

4.1 Is visual privacy important for the spatial quality of your dwelling?

R1: Not that important. You could just close the curtains when you want that.

R2: It's not very important.

R3: It's important, but as long as you are not recognized by face, its sufficient.

R4: Very important!

R5: It's important. The level of privacy I have is sufficient.

R6: Very important. Especially in the bedroom and study place, but preferably everywhere.

R7: It's important, but in my house it is great. Gallery next to the window would be horrible.

R8: It's important, but I think that how I have it now is great. It's more important at night.

4.2 How do you experience privacy/exposure in your dwelling currently?

R1: It is sufficient

R2: It's very good! I do not feel like it is affected by either surrounding buildings or streets as I am on the 13th floor.

R3: It's good, but could be better if I was less recognizable. One floor up would be perfect!

R4: It could be better, but it's not so bad.

R5: Not too bad.

R6: Quite bad, because of the opposite building. Especially when the trees don't have leaves.

R7: It's great!

R8: Very good!

4.3 Is it more important to have visual refuge from the street or the surrounding buildings?

R1: More from the opposite buildings, because they are fixed, but people walking by the street change all the time.

R2: Opposite buildings more, but also the street.

R3: More from the street.

R4: From the street is more important. When they are in the building they just do their own thing, but when on the street I feel like they look around more.

R5: Mostly from the street, but really depends on where you are more observed from.

R6: It's more important to have privacy from other buildings.

R7: Surrounding buildings, because it's more personal. Anyone could walk down the street and you don't really know them so it's fine.

R8: Its more important to not be seen from the street.

4.4 For which daily activities is privacy important for you?

R1: Only when sleeping

R2: Mostly sleeping and sometimes when working.

R3: Sleeping, getting dressed, and when lying down in bed.

R4: When sleeping and changing clothes.

R5: Mostly when sleeping and changing clothes.

R6: For anything, but most of all when studying and sleeping.

R7: Mostly sleeping, but preferably all the time.

R8: Mostly at night, then I feel very exposed because of the light.

4.5 How far can the observer be for you to feel like it is affecting your privacy?

R1: Further than the opposite building (23 meters) would not affect me much.

R2: About half of the distance to the opposite building (100 meters)

R3: The building on the opposite side is far enough (22 meters) for it not to affect my privacy?

R4: The opposite building is too close (22 meters). Further than the street nearby (60 meters) would be far enough.

R5: The street (39 meters) is far enough, but the path near my wall is too close (14 m)

R6: The opposite building is too close (47 meters). As long as it is permanent viewer-like from the surrounding housing then it really bothers me. For people on the street, closer is fine, but for opposite buildings, I would like them to be at least twice as far (94 m).

R7: About 20 meters would be far enough.

R8: If the observer is closer than 30 meters, I feel like that is too close.

5. Building Elements

5.1 How often do you keep your blinds closed during the day and why?

R1: Quite often because it is too bright. I would want blinds that would give me control over the level of brightness.

R2: Only when I experience glare, or when it is very cold and I feel the draft from the balcony door, through the gaps.

R3: Only when I experience glare during my studies. Not very often.

R4: Almost never. Only because of the glare sometimes.

R5: Never. If I would keep them closed then my plants would die.

R6: Almost always I keep them closed. They let through the light, but obstruct the view and give me privacy. Sometimes I keep the middle blind open in summer.

R7: Never

R8: Only when I am taking a nap, when there is glare, and when it is really hot in the summer.

5.2 How often do you keep your blinds closed at night and why?

R1: I always keep them closed at night because of the light.

R2: Usually I keep them partly open at night so that I would wake up with the sun in my room.

R3: In the evening when it is dark I keep them open, but at night around 22:00 when other people start closing them I close my curtains as well.

R4: Almost always, but sometimes I keep them open to see the night view.

R5: I always close them when it gets dark because of the privacy.

R6: Always closed.

R7: I close them an hour before going to sleep because it feels more private and light.

R8: When I plan to sleep little linger then I close them, but when I have to wake up early than I usually leave them partly open so I would wake up with sunlight in my face.

5.3 Have you arranged your furniture in a certain way to get a different level of daylight, view to the outside or privacy depending on the conducted activity?

R1: I keep changing the layout of my room seasonally. In the summer I put a couch next to the window. My bed is always next to the window because of the noise from my roommates. If there was no noise I would put my bed away from the window.

R2: Because the room is so small it's more about what fits where. But I do like to have the desk next to the window because of the daylight and view.

R3: Yes, I keep my bed in the most private corner. The table is next to the window because of the light and view. A North window with indirect sunlight would be best for studies.

R4: Bed in the most private spot and my shelf in front of it to block the view. The table is next to the window because of the daylight. Ideally, the kitchen would also be next to the window.

R5: More about the space and what fits where as long as the bed is not next to the window.

R6: Study table not facing the window as it gets me too distracted. But other than that I like to create zones each for their activity and then its just about what fits where.

R7: Bed in the back of the room because it's darker. Study space next to the window because of the light. Also, nothing that blocks light can be in the middle of the room.

R8: Everything except for the bed should be near the window. Desk must be next to the window.

5.4 Have you bought any furniture elements to adjust the level of privacy, view to outside or daylight (think of curtains or room divider)?

R1: I bought new curtains because the previous ones would let too much light through.

R2: No nothing. The curtains were already here.

R3: No, nothing. I like the curtains that were here already.

R4: Yes, I bought an additional shelf to put between the bed and the window. Also I bought mostly white furniture for it to reflect more light.

R5: Yes, I bought curtains that would block most of the light, but still let a little bit through.

R6: Yes I bought the blinds that let through light, but obstruct the view. I had Venetian blinds, but they didn't let enough light through. Also, view obstructing translucent window film I bought for privacy to put on the lower part of the window. If I would buy the blinds again I would buy them more yellow for warmer light.

R7: I bought the curtains because the room felt incomplete without them.

R8: I got curtains for light at night and heat in the summer.

5.5 Would you consider repainting the room to a brighter/darker color to change the general brightness of your room?

R1: I have repainted it white from yellow-white, but not so much because of the light color preference.

R2: It was white and I prefer that because it makes it feel more spacious. If the color were darker I would repaint it white.

R3: If it was a dark color I would repaint it to a brighter color for more light.

R4: I have one dark-colored wall and I am considering repainting it. As long as it is a bright color for the light I like it.

R5: Yes, I repainted one of the walls blue because of the accent. If the rest of the walls would be a dark color I would repaint them as well.

R6: If the walls would be dark in color then I would repaint them. I am considering painting a darker accent color around the bed, because of color, but not brightness.

R7: I repainted the room because the paint was bad quality. White makes the room brighter and I like that. I would paint it white from a dark color, but only if I live here for at least a year.

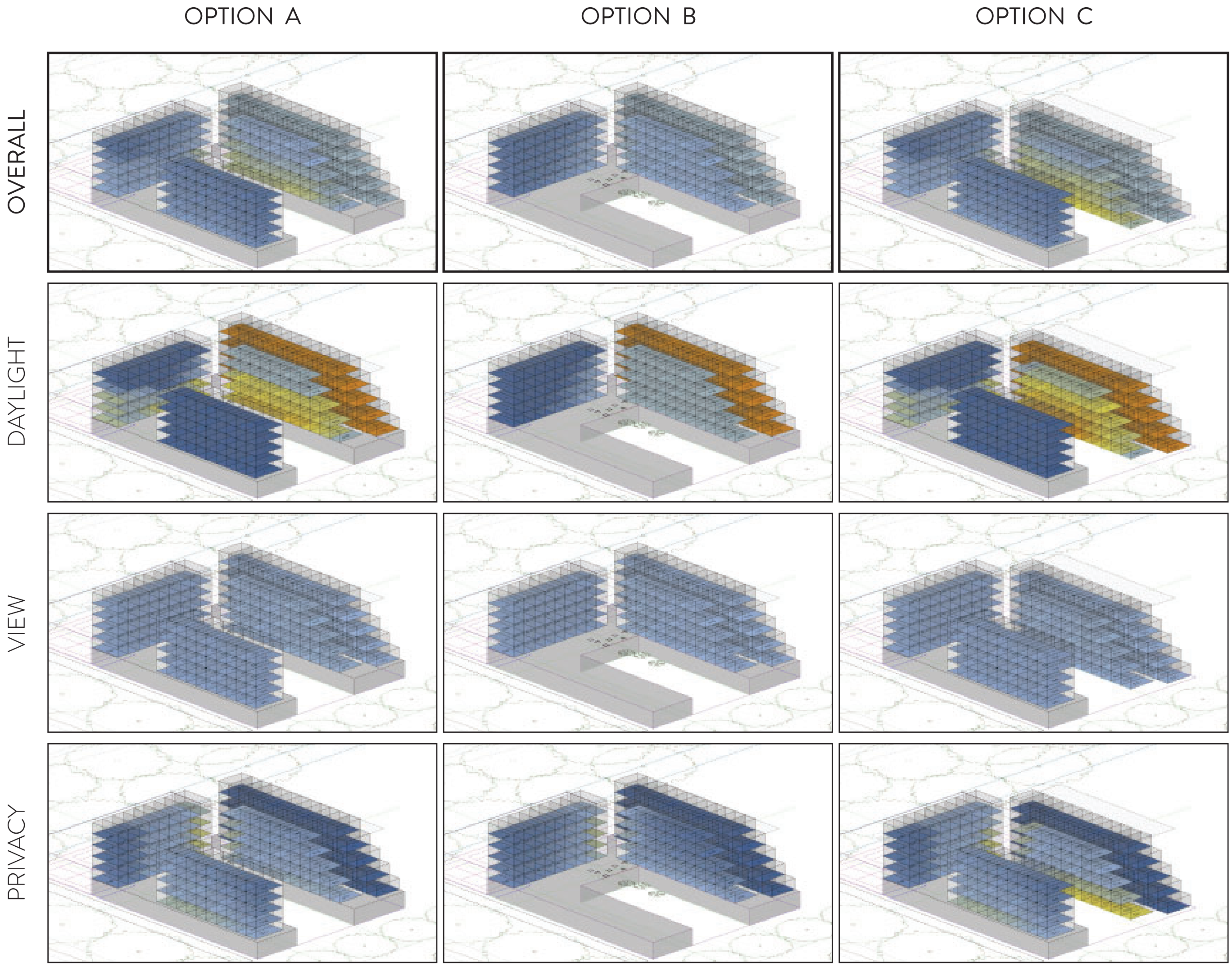
R8: I repainted the room from mint green color to white, because it was quite ugly color, but also makes the room feel more spacious, and bright. I would be all right with the darker colors as well as long as I have good artificial lighting.

APPENDIX C: PARAMETRIC EVALUATION MODEL INPUTS

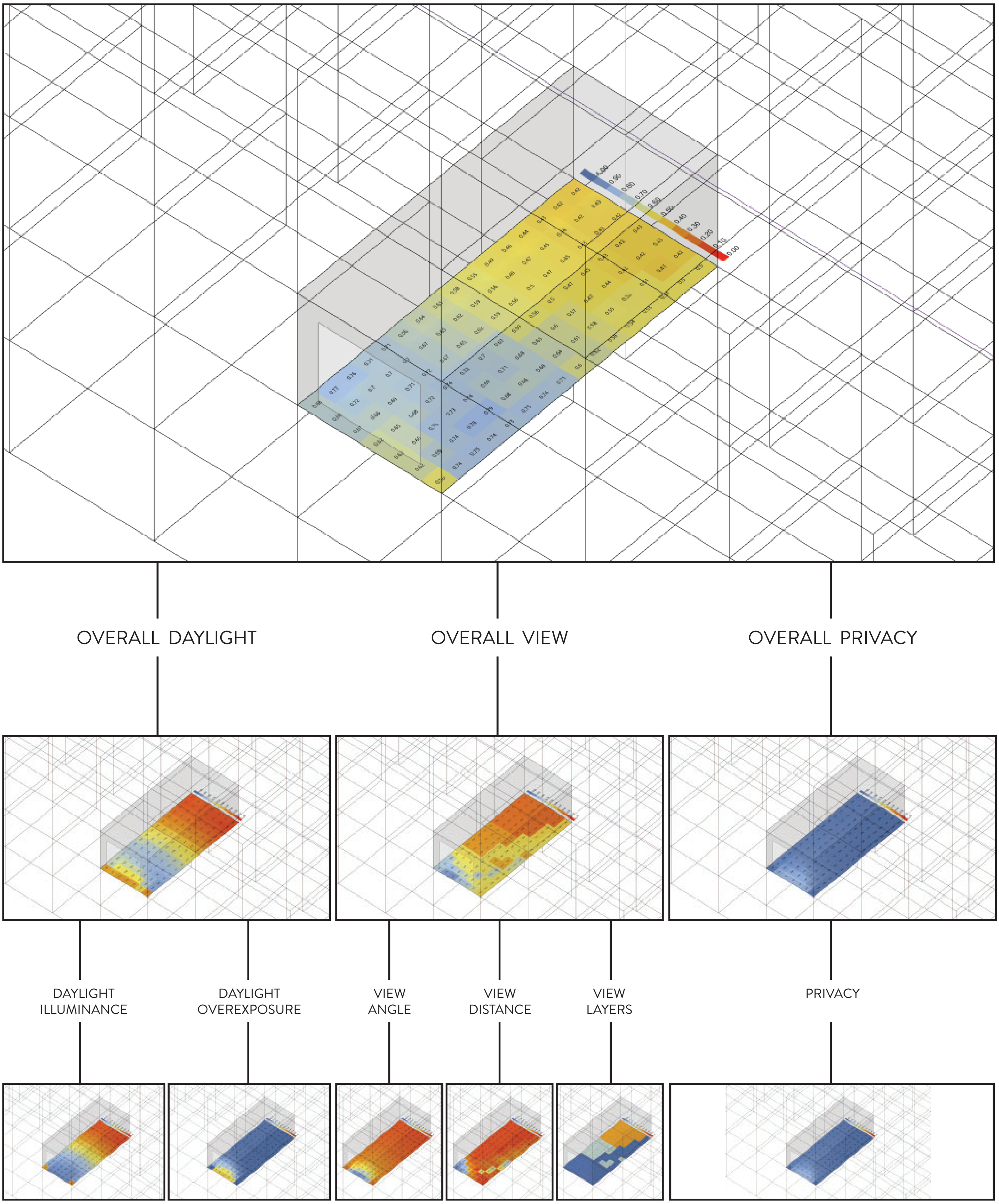
Input name	Data type	Short description input
True north rotation	Number	degrees rotation counter clockwise between true onrth and Y axis in the 3 D model.
Surrounding obstructions	Geometry	Any 3D geometry (mesh, surfaces, BREP) that might obstruct viewlines, but is not building itself. This may include greenery or context buildings among other obstructions.
Dwelling units ALL	BREP	Dwelling units are specified as individual BREP geometry. This is done in this way to give more flexibility in the design process and enable aditive designing by moving and adding new dwellings separately.
Dwelling unit SELECTED	BREP	On unit scale one dwelling is analysed at a time. This input specifies that dwelling, and it should be one of the dwellings that has also been specified in the input for Dwelling units ALL.
Building massing	BREP	Builing massing is the input specifying the envelope of the building. Since the dwelling units are referenced as separate BREP geometry, the surface center point of dwelling units is tested for its closest point to Building massing BREP surfaces to quickly separate unit exterior surfaces from the interior ones. If the distance is lower than 0.1 meters, the surface is considered to be exterior.
Window ratio	Number	This number in form of a slider input represents the proportion of the area of the window to the exterior surface it is part of. The proportion is between the surface areas, not the edges.
Unit Scale analysis grid	Number	Individual unit is analyzed on a scale of grid points and their orthogonal distance between each other. The smaller the scale the more accurate the results. With this input, the scale can be specified (default 0,5 meters).
All surfaces possible observers	Surface	To reference areas on which possible observers could be standing, this input is used. From these surfaces observer points are specified by dividing it in a grid of points.
Observer surface grid size	Number	This number represents the grid of point division size for the All surfaces possible observers input. The smaller the number the more precise the analysis will be.

APPENDIX D: PARAMETRIC EVALUATION MODEL RESULTS

BUILDING DESIGN OPTION COMPARISON



UNIT OVERALL VISUAL QUALITY



APPENDIX E: REFLECTION PAPER

In this reflection paper, I am looking back at my research and design process in the Architectural Engineering graduation studio. My ambition for the graduation project was to design student housing of increased spatial quality in Delft Campus. This I aimed to address with a parametric evaluation model that would be used extensively in early design stages in order to make more informed decisions with the help of data about evaluated visual spatial quality. In the following paragraphs, I will address the questions of the AUBS Graduation Manual.

What is the relationship between your graduation project topic, your master track and your master programme?

As a student in the architecture track, my responsibility is to design lived spaces and shape the experiences within them. For my graduation topic, I aim to delve into the housing experiences of one of the most financially limited social groups, namely students. Often, these individuals face challenges such as insufficient sunlight in their rooms or a lack of privacy due to their only window facing a busy street. As a student in the master's program at AUBS, I am exploring the potential of new computational technology tools to address this issue in the early stages of design.

How did your research influence your design/recommendations and how did the design/recommendations influence your research?

Besides building a parametric evaluation model that helped me to assign a "score" for the visual quality of each student dwelling unit, I gained valuable insights during my interviews with students while visiting their dwellings. The findings of these interviews were essential in creating the parametric model. For instance, I learned about how different students perceive the quality of daylight (overall brightness), direct sunlight, view, and privacy, and when they consider these qualities desirable. Consequently, my design process was guided directly by the insights I gained as well as the scripted parametric model, which also addressed the level of quality expressed by students and the literature review. On the other hand, my design influenced my research, as the parametric evaluation model and its input were based on the geometry I used during the mass studies of housing units.

How do you assess the value of your way of working (your approach, your used methods, used methodology)?

While there are likely many other research methods that could have been used to construct a parametric evaluation model, I specifically chose to use qualitative methods. I believed that these methods would provide me with valuable insights into student housing quality perception early in the process. Conducting semi-structured interviews within the dwellings of the interviewees allowed me to immerse myself in their living situations and gain a first-hand understanding of their spatial quality experience.
Although a quantitative approach such as surveys might have yielded more objectively comparable results for the parametric evaluation model, I considered qualitative methods like interviews to be more better suited in comprehending the overall perception of spatial quality by students. Unlike surveys, interviews permit follow-up questions, enabling a deeper exploration of the subject. However, to enhance the objectivity of the parametric model, it would be beneficial to study its results using more quantifiable methods and test its outcomes on a broader sample of individuals.

How do you assess the academic and societal value, scope and implication of your graduation project, including ethical aspects?

Traditionally, computational design has primarily been applied to perform straightforward calculations on a larger scale, aiming to assist the design process and enable informed decision-making based on the results. One of the most commonly assessed parameters in the design process using computational methods is the calculation of direct sunlight. However, computational models have the potential to indirectly involve stakeholders who typically do not participate in the design process, such as the end-users.

By thoroughly understanding the user group and their values regarding design qualities, a well-constructed evaluation model can, to some extent, identify areas where the design does not achieve their desired qualities. This, of course, requires comprehensive information from the user group and a computational model capable of assessing it. Subsequently, the results obtained would need to be validated. In my research and design work, I attempted to construct such a model to represent the desired qualities of students from the early stages of the design process. However, due to time limitations, I did not directly validate these results with the students, apart from seeking their feedback on how they would experience the dwellings I was designing.
Ethically, it is crucial to acknowledge that computational models can be easily misused by developers or other parties, who may manipulate the data to design housing that prioritizes profitability over quality. The quality of housing is always relative, as there is no one best design option. Instead, there are various design choices of higher or lower quality for different contexts and user groups. Therefore, a computational model must be used with caution, and the results should be validated transparently with users. It is essential to explicitly explain how the results are calculated, ensuring transparency and accountability in the design process.

How do you assess the value of the transferability of your project results?

The research findings obtained from interviews and literature review can directly inform the design process to better understand what aspects contribute to perception of spatial quality. Instead of a direct quantitative assessment, these factors are taken into account during design process.
However, it should be noted that the constructed parametric evaluation model can only be used in a different project with certain modifications and primarily for gaining insights, rather than objectively expressing the quality of housing. The model can assist in identifying dwelling units that may be highly exposed (lacking privacy) or where sunlight may be insufficient. Nevertheless, these indications are not absolute truths but rather serve as guides.

Own question 1: Does the parametric evaluation model represent the needs of the student?

While the evaluation model aims to address the qualities that students prioritize in their housing, it is important to recognize that it covers only a fraction of their overall needs. The assessment of quality primarily relies on a limited set of parameters. For instance, when evaluating the view quality, the presence of greenery has not been included. This omission is due to time limitations in incorporating it into the model and the substantial effort required to input 3D geometry representing the presence of greenery.
Furthermore, it is essential to note that student housing units only attempt to meet the most fundamental needs of students. They do not account for the students requirements for social interactions, which are crucial in the design of collective spaces. These aspects, which involve creating spaces that foster social connections and community engagement, are beyond the scope of the evaluation model.

Own question 2: What role does the computational model play along traditional design process

The computational model should be viewed as an addition to the traditional design process rather than a substitute for it. It serves as an additional tool to obtain deeper insights and compare various design alternatives more efficiently. These results can then be utilized to make informed improvements in the design, such as considering different typologies or altering the assembled mass.
By integrating the computational model into the design process, designers can streamline their decision-making and gain valuable insights that might otherwise require significant effort and time. However, it is important to remember that the computational model is not intended to replace the traditional design process, but rather to enhance it by providing data-driven perspectives and highlighting areas that require attention and refinement.