Abstract. Traditional Korean architecture provides privacy through a proper balance of openness and enclosure through courtyard gardens. However, it is difficult to analyse privacy quantitatively in a three-dimensional space. The analysis of visual privacy is a significant issue in resolving conflicts and enhancing comfort. This paper develops a computational algorithm for simulating and measuring privacy on the concept of prospect and refuge: a design strategy for psychological well-being. In order to visualize privacy, the prospect area ratio (PAR) and refuge area ratio (RAR) are used in 3D visual simulations. PAR and RAR calculate the area ratio of the hiding space or the visible space in the images collected from the 3D model. In addition, parametric algorithms are proposed to calculate PAR/RAR automatically. Finally, this research demonstrates a case study of Gyeongbokgung, one of the five palace buildings in Korea, to show methods and processes of the quantitative analysis of visual privacy. The outcome of this paper contributes to quantitative confirmation of spatial characteristics that clearly distinguish between public space and private space of Gyeongbokgung. The proposed method also shows great potentials to quickly obtain the numeric value of privacy.

Keywords. 3D simulation; numerical measurement; traditional Korean palace; privacy.
visual privacy for the well-designed space. For the purpose of this paper, visual privacy is defined as the ability that a person can see others and can adjust interaction with the outside at any time without being observed by others outside (figure 1a). Visual privacy could be achieved through the adjustment of boundaries and territories in a physical environment (Kaplan and Kaplan 1989; Kelvin 1973; Newell 1995). This shows that visual privacy is connected to the prospect and refuge theory (figure 1b). This paper tackles computational simulation and quantitative analysis of visual privacy to get optimal design in terms of prospect and refuge.

![Figure 1. The representation of concept: (a) visual privacy (Al-kodmany 1999, p. 283), (b) prospect and refuge (Appleton 1975, p. 76).](image)

Traditional Korean palaces represent the architectural style of Korea and play an important role in the study of history as the use of space is clearly divided according to the life of the Royal Family. These palaces regionally appear to have an obvious space configuration according to spatial function (Kim and Joo 1983). Typically, their spaces are arranged in order of increasing privacy from public areas of the palace entrance to private spaces at the back of the site: public areas, where national events and state affairs were held, and private spaces, where everyday activities such as sleeping and resting are performed. However, many architectural researches on traditional Korean Palaces are focusing on qualitative analysis of their spatial, shape, color, material characteristics (Kim and Joo 1983; Yang and Cheon 2011; Chen et al. 2015). Because of the obvious space configuration according to spatial function by region in traditional Korean Palaces, considerable differences in visual privacy values are expected. In order to verify this, visual simulation and algorithms for numerical measurement of privacy are developed.

This research describes a method for visual simulation and numerical measurement of the spatial property of visual privacy, dealing with the digital modelling which is involving parametric design. First, this paper explains how to simulate visual privacy with the prospect area ratio (PAR) and refuge area ratio (RAR). PAR is the quantification of the ratio of the prospect area and RAR, the area ratios of concealed space, in 3D simulation. For the 3D simulation of PAR and RAR, exterior views looking into the inside from outside the space are considered to suggest a visual perception analysis method according to the walking paths. Second, in order to choose main paths and set observation points and view automatically, parametric values of are inputted. PAR/RAR calculating methods are developed
applying different parameter values for selecting main paths, the number and the
heights of observation points and the view in observation points. In addition, para-
metric algorithms are proposed to calculate PAR/RAR automatically. Finally, this
research demonstrates a case study of Korean traditional palace to show methods
and processes of the quantitative analysis of visual privacy.

2. 3D Visual Simulation

In research by Dawes and Ostwald (2014), for spatial visual perception properties,
the isovist area was quantitatively evaluated for analysis from the point of view
an observer within that space. Lim et al. (2010) employed a visual access and
exposure (VAE) model in order to quantify visual privacy from a random point
within a space. While these researchers used 2D or 3D models and selected an
observer point in indoor spaces according to perceived visual quantification, there
was no consideration of the view looking into the inside from outside the space
to evaluate privacy of buildings. Therefore, this research commences with the
observer’s view, taking into account the view from the outside of the building.

2.1. 3D MODELING

In the analysis of the overall characteristics of visual perception in 3D modelled
buildings, it is essential to ensure a model’s accuracy and practicable processing
times (Bhatia et al. 2012). As there is a need for a high level of computing power
to manage the data in 3D design, research on the actual application of the 3D
simulation images is not much because of the software and hardware limitation.
In response to the need for 3D visual simulation, Rhino (Rhinoceros 5) is used to
provide a simple format of an architectural model. The buildings to be analysed for
visual privacy are modelled in 3D using Rhino, leaving out intricate details such
as decorations and textures. The shapes of the buildings are modelled considering
general geometric properties, size, and building openings.

On the 3D model, main paths are suggested for walking through 3D buildings
to set observation points (OPs). OPs are selected at regular intervals from the
exterior to the main entrance of the building (for refuge area) or within the interior
of the building (for prospect area). According to the path, images looking in or
out of the buildings from the eye level of an observer (ex) 1.6 m) at each OP are
captured and collected using the camera lens length (ex) 50.0) in Rhino.

2.2. 3D SIMULATION OF PAR, RAR

In the view from the exterior of a building into the interior, the indoor exposure area
that can be seen through openings (doors and windows) is extracted. Within the
entire image, after excluding the indoor exposure area, the remaining area is called
the refuge area (RA), into which one cannot look. For images looking outward at
OPs selected in the interior of a building, prospect area (PA) is extracted. As
prospect is an unimpeded opportunity to see (Appleton 1975 in Stamps 2008) and
the visual experience of subconsciously looking outward through openings (Kim
and Kim 2004), the study includes everything to see as a prospect area with the
exception of the buildings. Prospect area ratio (PAR) and refuge area ratio (RAR)
are calculated representing the proportion of PA or RA among all areas of view.

In order to visualize privacy in 3D simulation, rays at regular intervals are send from an observation point to target area surface (figure 2a). It is tried to select any rays transmitted through the opening into the inside of building for indoor exposure area (figure 2b). It is the RA that excludes indoor exposure rays from all rays. On the other hand, for the PA, rays meeting a given building excluded from whole rays.

![Figure 2. 3D simulation of RAR: (a) rays from OP (b) selection of indoor exposure area.](image)

3. Numerical Measurement

This section provides the algorithms for numerical measurement of privacy using PAR and RAR in 3D simulation, and it is divided into three steps: selecting the main path and the observation points, setting view in observation points, automatically calculating PAR/RAR. These algorithms are developed with Grasshopper.

3.1. SELECTING THE MAIN PATH AND THE OBSERVATION POINTS

The first step involves constructing the grid which is used to create the observer points in the surface which the main paths pass over at the eye level of the observer (figure 3a). The number of grids and the height of observation point are used as parameters (figure 3b).

![Figure 3. (a) Parametric definition of grid for setting observation point (b) Parametric values of grid.](image)
In the next step, generating algorithm is developed in order to select an observation point on the grid. These points can be chosen at the grid intersection created above. Depending on the number of grid in the surface generated in the further stages, various distances between the observation points are also defined by means of parameters. Parameters located in uv domain within the grid. In addition, the main path is established automatically after selecting each observer point.

3.2. SETTING VIEW IN OBSERVATION POINTS
This second exploration with parametric design method involves setting view which accommodates any possible camera lens length, camera target point and camera view point. In the observation points, these parametric variables have settled view range of images.

In order to collect images looking inside the building from each observer point, each observation point is set as a camera viewpoint according to the main path. In addition to camera lens length, various horizontal distances between a camera viewpoint and a camera target point are defined by means of parameters.

3.3. AUTOMATICALLY CALCULATING PAR, RAR
To calculate automatically PAR and RAR, algorithms for trying to isolate rays transmitted through the opening into the inside of building and rays blocked on the building surface from whole rays are developed (figure 4).

![Figure 4. Automatic calculation of refuge area ratio and prospect area ratio.](image)

4. Case Study
In this chapter, the verification process of the automatic calculation algorithm of PAR and RAR is described in a case study. Gyeongbokgung is selected for the verification experiment, which is the main royal palace of the Joseon dynasty located in northern Seoul, South Korea. It regionally appears to have an obvious
space configuration according to spatial function. In Gyeongbokgung, spaces are arranged in order of increasing privacy from public areas of the palace entrance to private spaces in the back: Geunjeongjeon as a public space, where national events and state affairs were held, and Gyotaejeon, which are private spaces where daily life occurred.

4.1. 3D VISUAL SIMULATION
Since royal palaces in Korea have complex forms and ornamentation, the lines that compose the forms are very complicated. Therefore, this study used Rhino (Rhinoceros 5.0) to provide a simple building shape for the palaces in our 3D models, based on the 3D spatial information on the Vworld. Vworld is spatial information open platform which the Korean Government built to provide 2D and 3D spatial information of Korea (Vworld 2016).

4.2. NUMERICAL MEASUREMENT
When the parametric values are inputted in the proposed algorithm, the RAR values are automatically calculated. Table 1 shows parametric values and inputted value to measure RAR in this case study. The comprehensive graphs of calculating RAR results describe the quantification of RAR in figure 5 and figure 6.

<table>
<thead>
<tr>
<th>Table 1. Parametric values and Inputted values.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observation point selection</strong></td>
</tr>
<tr>
<td>OP¹</td>
</tr>
<tr>
<td>OP²</td>
</tr>
<tr>
<td><strong>View selection</strong></td>
</tr>
<tr>
<td>VS¹</td>
</tr>
<tr>
<td>VS²</td>
</tr>
<tr>
<td>VS³</td>
</tr>
<tr>
<td>VS⁴</td>
</tr>
</tbody>
</table>

Overall, the progressing aspect of the graph for RAR shows weaker levels of refuge closer to the building. The maximum value for RAR of 1.00 denotes that the interior of a building is not visible from the exterior, while lower values represent that the interior is largely exposed to the exterior.

In the analysis of refuge areas visible from the main regions of Gyeongbokgung, the level of RAR is generally high in private areas, and its average value is close to 1.00. On the other hand, public spaces have lower values to a certain extent compared to private spaces. As shown in figure 5 and figure 6, in Geunjeongjeon of Gyeongbokgung, the RARs along the path relatively suggest substantial variation (RAR=0.94→0.26). On the other hand, Gyotaejeon, the private space of Gyeongbokgung shows a refuge-dominant area. By the time the visitor approaches the gate, the main building finally could be seen with continuous declining the value of RAR (RAR=0.88→0.56).
Figure 5. Refuge Area Ratio (RAR) graphs of Geunjeongjeon.

Figure 6. Refuge Area Ratio (RAR) graphs of Gyotaejeon.

Table 2. Prospect Area Ratio (PAR).

<table>
<thead>
<tr>
<th>Observation Point</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gyeongbokgung</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geunjeongjeon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front</td>
<td>0.3</td>
<td>0.2</td>
<td>0.22</td>
</tr>
<tr>
<td>Back</td>
<td>0.03</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>Gyotaegeon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Back</td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
</tr>
</tbody>
</table>
By comparing quantitatively analysis of PAR resulting from 3D models in table 2, it shows the rate of area could be seen from inside to outside, excluding buildings. The level of PAR is shown to be slightly higher in front of Geunjeongjeon than in the back, since the back of Geunjeongjeon are relatively more blocked by walls and other buildings while providing extensive courtyard in front of these buildings. It means that visibility is provided in the front view of public spaces. On the other hand, since Gyotaegeon are rather adjacent to and closed by other buildings as a private space, it illustrates low level of prospect both front and back of the buildings.

5. Conclusion
This paper investigates the integration of computational simulation and quantitative analysis of visual privacy to get optimal design in terms of prospect and refuge. The method of simulation is developed for automatic measurement of PAR and RAR using different kinds of parametric values. This research presents an integration of two different digital tools: Rhino, Grasshopper. They are used to develop algorithms for setting 3D visual simulation and automatic measurement of PAR and RAR.

5.1. CONTRIBUTION
The greatest significance of this study is increasing usability by introducing 3D visual simulation and parametric algorithm. In 3D models of buildings, experimental research could be conducted without being constrained in time and without disturbances from surroundings. As a result, higher accuracy rates and time-saving are achieved, as there is no limitation on obstruction of visitors, constraint approach and weather restrictions in real time.

The proposed parametric algorithm in this paper has great potentials to quickly obtain information about the results of evaluating visual privacy at multiple points. Therefore, one of the most important outcomes of this study is providing an algorithm for designers to evaluate visual privacy for optimal control in the early design stage.

5.2. ISSUE
An issue that was not addressed in this study is whether RAR and PAR are absolute values that represent the amount of privacy. Nevertheless, since the proposed approach can quantitatively indicate the change of visual privacy according to the actual view along a path, it is expected to be very useful when planning spaces to provide privacy in the future. Moreover, in this paper, there are issues of investigating only front view and one main path with one case. This is the beginning of attempts to quantify the visual privacy of spaces using the concept of prospect and refuge; future studies that evaluate visual privacy quantitatively using various views and paths are expected with the algorithms of numerical measurement and automatic calculation.
5.3. APPLICATION

As this study commenced with Palace case study, the proposed algorithm needs to be more elaborated through another case study. More broadly, this research will serve as a base for future studies that this image analysis method of PAR and RAR could be applied to a wide range of architectural planning and design: a residential, healthcare and other buildings in which visual privacy is significant.

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