A Quantitative Analysis of Natural Surveillance at Elementary Schools
-Evaluation Method Based on Perspectives from Both Outside Visibility and Visibility from Inside Buildings-

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Abstract
In recent years, there has been increased demand for the development of an effective way of addressing the somewhat contradictory topics of opening schools to the community and crime prevention. In response to this demand, there has been a rise in the active usage of theory of crime prevention through environmental design (CPTED). Natural surveillance is particularly important in CPTED, and there has been a proposal to increase crime prevention efforts based on natural surveillance by using layout and floor planning studies, in addition to previous elementary school facility planning models that have focused primarily on the function and design of schools. For this reason, it has become necessary to develop a method to quantitatively evaluate the natural surveillance of elementary schools. The authors proposed a method to evaluate natural surveillance from two perspectives — the view of the school grounds from outside and the view of the exterior from inside the buildings — for 46 elementary schools, for the purpose of gaining knowledge concerning the factors that make elementary schools safe or unsafe.

Keywords: CPTED; exterior natural surveillance; outward-looking natural surveillance; non-visibility region; visible space

1. Introduction
In recent years in Japan, elementary schools have been expected to serve not only as centers for primary education, but also as community bases, and there have been many cases in which empty classrooms and schoolyards have been opened to the community. However, in the wake of the 2001 Ikeda Elementary School massacre in Osaka, awareness of the safety of pupils has risen, and there has been increased demand for the development of an effective way of addressing the somewhat contradictory topics of open schools and crime prevention.

In response to this demand, there has been a rise in the active usage of the theory of crime prevention through environmental design (CPTED), a theory aimed at creating an environment that limits the chance that crimes may occur through analysis of the environmental and spatial components that lead to opportunistic crimes¹. Considerable research has been done in this vein, such as that conducted by Jeffery (1971) and Newman (1972). One of the key elements in CPTED is maintaining surveillance of criminals.

Crowe (1991) places surveillance types into the three categories of natural (surveillance from windows and other areas with the human eye), organized (police patrol surveillance and other such measures), and mechanical (surveillance through cameras and other technology). The focus of maintaining surveillance is on taking advantage of natural means. Meanwhile, there are also calls to recognize the importance of combining the four elements of CPTED² in as comprehensive and natural a way as possible with other fields of study, and making use of a number of techniques to develop all of these (Anzen-anshin matidukuri kenkyukai, 1998). Thus, natural surveillance is particularly important in CPTED, and there has been a proposal to increase crime prevention efforts based on natural surveillance using layout and floor planning studies, in addition to previous elementary school planning models that have focused primarily on the function and design of schools. For this reason, it has become necessary to develop a method to quantitatively evaluate the natural surveillance of elementary schools.

In the Japanese Ministry of Education, Science, Sports, and Technology’s (MEXT) *Guidelines

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for Designing Elementary School Facilities", an importance is placed on "maintaining visibility from school grounds, inside school buildings and the outer area of the school grounds, and removing blind spots." Thus, the authors propose a method to evaluate natural surveillance from two perspectives — the view of the school grounds from outside and the view of the exterior from inside the buildings — for 46 elementary schools, for the purpose of gaining knowledge concerning the factors that make elementary schools safe or unsafe.

2. Where Previous and Current Research Stand

Some previous natural surveillance research has focused on building windows. Ono, et al. (1995) did research on housing complexes and evaluated the natural surveillance level by measuring the amount of visual radiation that emanated from building windows at a given point. Koike, et al. (2008) focused on residences and developed a system that visualized the extent of natural surveillance from sidewalks to the target windows using a light-projection method in order to quantitatively evaluate the break-in risk of individual windows. The authors also conducted quantitative research to understand the natural surveillance of elementary schools through the measurement of three-dimensional visibility levels of windows (Fujii, et al., 2011, 2012).

Meanwhile, natural surveillance research focused on views of exterior spaces was also undertaken. Nagaie, et al. (2007) focused on urban space and made an analysis of visibility based on Axial line and Isovist on Space syntax theory in order to clarify the dead area. Takizawa, et al. (2010) focused on street crimes and investigated the relationship between snatch theft and the spatial attributes of the suburbs of Kyoto City. The spatial attributes considered include demographic data, land-use, visibility of space, and illuminance on the street.

In addition, researches concerning crime prevention included those that determined criminal spots on the way home from school in the Gangseo district for middle-school students through a cognitive map analysis (Lee, et al., 2012); that related the characteristics of the roads in a target area with the feeling of insecurity of the elderly concerning snatch occurrences on these roads through correspondence analysis (An, et al., 2011); that analyzed the affect factors regarding the security and situation construction of public spaces on a college campus (Wang, et al., 2011); that proposed an effectiveness evaluation method for a crime prevention system which combined the advantages of the analytic hierarchy process (AHP) and a clustering method (Bu, et al., 2010); that developed the dynamic pattern analysis framework (DPA Framework) for cooperative crime prevention (Leong, et al., 2008), and so on.

The authors also researched visualization and quantification for visibility regions, using image-processing techniques to judge the visibility of specific elements of random points. Attempts were made to analyze the visibility of Minarets in San'a old city Yemen (Oikawa, 2004); analysis of effects of ground shape on visibility (Oikawa and Kanatsuka, 1998); analysis of visual characteristic of architectural space by solid angle (Miyoshi, et al., 1997), and so on.

Until now, the results of individual analyses regarding the visibility quality of exterior space and views from windows of buildings have been the focus of natural surveillance research. However, natural surveillance evaluation methods that integrate these results have not yet been reported. The research on this topic is seeing the development of new standards that evaluate the natural surveillance of elementary schools based on the two perspectives of building exterior visibility and the views from building windows.

3. Method of Evaluation of Natural Surveillance at Elementary Schools

(1) The definition of visibility and natural surveillance

In this research, visibility refers to the condition where the line of vision connecting a random observing point and a random target point at the center of a given spatial mesh is not screened (Fig.1.). The total number of observing points that have visibility at a random target point in the measurement area is defined as the natural surveillance level.

(2) The exterior natural surveillance level and the outward-looking natural surveillance level

Here, the natural surveillance level of building exteriors is defined as the exterior natural surveillance level (Fig.2.), and the natural surveillance level of exterior areas from building interiors is defined as the outward-looking natural surveillance level (Fig.3.).
Based on this model, it is possible to evaluate natural surveillance based on the visibility of school building exteriors and on views from school building interiors.

3) Natural surveillance measurement method and targets as applied in this research

Measurement of the level of natural surveillance is done on all target points with set conditions for the measurement area's shape, screens, and mesh dimensions. The measurement area is the boundary of the elementary school's grounds, and the only screens considered are the edges of the buildings. Mesh dimensions are set at 1 m angles, taking measurement accuracy and calculation into consideration. In addition, the windows of rooms that regularly contain teachers such as classrooms, teachers' offices, teacher's working spaces, as well as the principal's office, or the nurse's office (hereafter called effective windows) were eliminated from the screens when measuring the outward-looking natural surveillance. Because of this, it is possible to perform measurements in line with real conditions with regard to the transparency of the line of sight through windows with routine supervision by teachers. The school building's interior observing points were set at 500 mm intervals on a line offset 500 mm to the inside of the effective window (Fig.4.). Concerning multi-storied elementary schools, measurement of the outward-looking natural surveillance level was provided by summing results calculated two-dimensionally based on each floor plan. An original program based on the C programming language was used for the calculations.

The research target was 46 schools that met the analysis criteria. The chosen schools were limited to those that had been opened in the period from 1980 to 2009 and had appeared in the magazine Shin Kenchiku.

4) Analysis index

The analysis index uses numerical indices based on the calculated values of each mesh (Table 1.) and on value-change drawing indices (Table 2.). Exterior natural surveillance ratio, α, is the ratio of exterior natural surveillance level to the total number of observing points in the measurement area. Outward-looking natural surveillance level, β, is the natural surveillance level of exterior areas from building interior observing points. Natural surveillance regional category charts are those that integrate the measurement of two perspectives into one drawing index by superposing the measurement results of the exterior and outward-looking natural surveillance levels and categorizing the space into sections, as indicated in Fig.5. In this way, it is possible to diagram extremely weak natural surveillance regions where exterior visibility is poor and there is no view from inside school buildings. Section IV of Fig.5. is defined as the non-visibility region, and the area of non-visibility region, γ, is calculated.

4. Natural Surveillance Measurement Results

1) Analysis of examples of natural surveillance in elementary schools

Four schools were chosen from the 46 target schools; analysis results are shown in Fig.6. Among the four chosen schools, Tozuka Minami Elementary School in Kawaguchi City had the highest α and β averages. In fact, it had the highest β average among all 46 schools. However, γ was 21.1% (fifth out of 46 schools), which is very high. There were a large number of effective windows facing the schoolyard, and a wide area of both high α and β values, centered on the schoolyard, was formed. Meanwhile, as the distance between school buildings and the boundary of the school grounds (range A) was narrow and no effective windows existed, low α and β regions were formed. Like regions with low α and β, it appears that non-visibility regions formed over a wide range. There is almost no view from the interior toward the region with poor visibility of the exterior, because section III (α < 25% and β ≥ 1) was only 0.8% of the exterior area.

The school with both the highest γ and γ of the four was Tamatsu Dai-ichi Elementary School in Kobe City. Its values for γ (4197 m²) and γ = 25.8%) were also second out of all 46 schools. In this example, too, the distribution trends of α and β are similar when we look at the isograms of α and β. Courtyards surrounded by buildings (range B) fell into section III (area rate 10.3%) based on the effect of outward-looking natural surveillance from classrooms, but there were almost no other instances of outward-looking natural surveillance for regions where α < 25%, meaning that non-visibility regions were widely present (range C).
At Nagisakoen Elementary School in Hiroshima City, as there are a large number of buildings, external space has been subdivided, and many regions of low $\alpha$ exist. The area rate of regions where $\alpha < 25\%$ is 42.3%, the second-highest out of all 46 schools. In the pilotis space (range D) enclosed in the building located in the site's center, and in ranges E and F near the boundary, where $\alpha$ and $\beta$ are both low, they are non-visibility regions. However, $\beta$ average is 94.5 units/m$^2$ and comparatively high; a wide region of section III (area rate 28.1%) is evident between the school buildings and the gym (range G), and $\gamma$ is kept at 14.2% (17th out of 46 schools).

Josei Elementary School in Naha City has a large range with low $\alpha$ in the courtyards and surroundings (range H) due to the effect of its intricate building formation; along with the lowest average $\alpha$ among the 46 schools, its area rate for regions where $\alpha < 25\%$ is also 48.5%, the highest out of all 46 schools. In addition, its $\beta$ average is also the lowest among the four schools, and cannot be called a high value because it is the 14th-lowest among all 46 schools. However, as many effective windows exist, facing regions of $\alpha < 25\%$ in courtyards (range H) as well as near the boundary of the school grounds (range I), section III, forming an extremely wide range for the external area (area rate 42.0%), is unique. The $\gamma$ of 784 m$^2$ and $\gamma_i$ of 6.6% are both the lowest among the four schools, while $\gamma$ is the ninth-lowest and $\gamma_i$ the seventh-lowest among all 46 schools.

This research evaluated natural surveillance based on both the visibility of school building exteriors from outside the buildings and the view of the exterior from inside the buildings. By superposing these and by calculating non-visibility regions, this research was able to analyze the natural surveillance of elementary schools in an integrated manner. Based on just these four examples, even if the $\alpha$ and $\beta$ averages are comparatively high (as, e.g., for Tozuka Minami Elementary School), examples of non-visibility forming over a wide range can be seen, while even if the $\alpha$ and $\beta$ averages are comparatively low (e.g., Josei Elementary School), examples of non-visibility regions forming and being limited to narrow ranges can be seen. Therefore, when undertaking an evaluation of natural surveillance, one must pay attention not only to the $\alpha$ and $\beta$ averages but also to the distribution characteristics and overlap of regions where the various values are low. This is essential to evaluate the natural surveillance of schools.

(2) Statistical Analysis of the 46 Schools

The results of the analysis of the 46 schools...
Almost three-quarters of the elementary schools were at $\alpha \geq 50\%$ (Fig.7.). It is thought that this result is largely due to the schoolyards that exist in all elementary schools. The average for all 46 schools was 54.34%; the highest value was 78.8% (Miyagawa Elementary School in Ashiya), and the lowest was 26.0% (Josei Elementary School in Naha). Thus, even though all the schools had schoolyards, a big difference could be seen. There is a trend where many elementary schools with a large average $\alpha$ take a rectangular shape and the school buildings are arranged close to the boundary of the school grounds. Meanwhile, schools with a small average $\alpha$ have facilities arranged close to the center of the school grounds and have buildings of a comparatively complicated configuration with courtyards and pilotes; we can see a trend of examples where the exterior space is subdivided in several areas. Furthermore, regardless of the size of average $\alpha$, there is a trend where $\alpha$ is low in the region between the boundary of the school grounds and the school buildings.

Concerning $\beta$, almost three-quarters of the elementary schools had $\beta \geq 40$, and around a quarter had $\beta \geq 80$. Most schools had $\beta \leq 100$ (Fig.8.), but a markedly high $\beta$ was seen in Tozuka Minami Elementary School and Miyagawa Elementary School. This is due to the fact that $\beta$ is extremely large when a large number of windows face the schoolyard. In these examples as well as others, we can see a bipolarizing trend of regions with high and low distribution in examples where effective windows were placed primarily on the side facing schoolyards.

It was discovered that about one-third of schools had $\gamma_a \geq 2000 \text{ m}^2$ (Fig.9.), and over half had $\gamma_r \geq 10\%$ (Fig.10.). High values for both $\gamma_a$ and $\gamma_r$ were seen in Tamatsu Dai-ichi Elementary in Kobe, Shimoyamada Elementary in Yamada, Komagamine Elementary in the town of Shinchi, and Shiraiashi Dai-Ni Elementary in Shiraishi. A wide range of non-visibility formed in cases where the distribution trends of $\alpha$ and $\beta$ were similar to one another. As an overall trend, resulting from the fact that elementary schools require space for a schoolyard, examples of school buildings placed close to the boundary of the school grounds were numerous, and regions with a low $\alpha$ between the boundary and the school buildings had a tendency to form. On top of this, in cases where effective windows were designed on one side facing large exterior spaces like schoolyards, both $\alpha$ and $\beta$ were lower in regions between the boundary and the buildings, and many wide non-visibility regions were formed. Finally, in cases of complex or divided building arrangements, outward-looking natural surveillance was not maintained toward small, fenced-in exterior spaces, and many partial non-visibility regions were formed.

Fig.11. shows that most schools were distributed in the region where $40 < \text{average } \alpha \leq 70$ and $20 < \text{average } \beta \leq 100$. Tozuka Minami Elementary School in Kawaguchi and Miyagawa Elementary School in Ashiya showed characteristic distributions.

5. Proposal for the Installation Position of Security Cameras

Regarding Komagamine Elementary School in the town of Shinchi, which had high values for both the area and area ratio of non-visibility regions, improvement of the surveillance level is proposed to show the practical application possibilities of this research. There are various ways to improve the surveillance level, such as renovating windows and enhancing the framework for patrol. As an example, efficient installation positions for security cameras...
were determined based on an understanding of the non-visibility regions.

Fig. 12. shows the natural surveillance regional category chart of Komagamine Elementary School in the town of Shinchi. \( \gamma_1 \) is 4642 m\(^2\), and \( \gamma_2 \) is 20.8\%. Generally, equipment is introduced by considering the angle of view and distance to an object, but this example installation was evaluated according to the following four conditions. i) Security cameras were installed on the exterior wall of the school building. ii) The angle of view was 60\(^\circ\). iii) The security cameras can observe objects within 30 m. iv) Five security cameras were installed.

Fig. 13. shows an example installation position of security cameras in Komagamine Elementary School. The values for \( \gamma_1 \) and \( \gamma_2 \) were recalculated except for the ranges observed by the security cameras. The calculated \( \gamma_1 \) was 2555 m\(^2\), and \( \gamma_2 \) was 11.4\%. According to this example, installing the security cameras decreased these values by about half.

6. Conclusion

This research has proposed a method for evaluating natural surveillance in schools from the perspectives of outside visibility and visibility of the exterior from inside the buildings, and natural surveillance in 46 elementary schools has been evaluated. The main results are summarized below.

1. Where school buildings are placed in proximity to the boundary of the school grounds and a large schoolyard is maintained, there is a trend towards high average values for exterior natural surveillance, \( \alpha \). However, there are many cases in which regions of low \( \alpha \) form between the boundary of the school grounds and the school buildings.

2. Where there are multiple or complex building layouts, there tends to be an observable trend where exterior space is subdivided and the average values for exterior natural surveillance, \( \alpha \), is low.

3. Outward-looking natural surveillance, \( \beta \), is strongly dependent on both the placement of rooms where teachers are always present and the window design. Furthermore, in examples where effective windows are primarily facing towards a schoolyard, bipolarization of \( \beta \) between the schoolyard and other external spaces is seen.

4. Non-visibility regions, where the level of natural surveillance is extremely weak, develop based on the similarity in the distribution trend of \( \alpha \) and \( \beta \). In order to avoid this, it is necessary to examine building arrangement and effective window arrangement in order to compensate for poor visibility of exterior spaces with views from inside school buildings. In particular, it is essential to maintain outward-looking natural surveillance toward small surrounded exterior spaces and spaces between the boundary of the school grounds and the buildings.

The results of this research can serve as basic data for practical planning in elementary schools considering strategies for crime prevention through natural surveillance. At the same time, the proposed evaluation method can be used as a theoretical examination tool in elementary school crime prevention. Topics of further research will include the relationship between the distribution of places where suspicious persons have been reported and that of places with high levels of insecurity regarding crime, and the distribution of exterior natural surveillance levels, outward-looking natural surveillance levels, and non-visibility regions.

Endnotes
1. "Opportunistic crimes" are the crimes which potential criminals carry out depending on circumstances and opportunities. Invasion crimes and street crimes correspond to this.
2. Target hardening, access control, maintaining surveillance, and territorial reinforcement are regarded as the four elements of CPTED.
3. Fujii, et al. (2011, 2012) focused on the views from school building interiors and attempted to understand in detail the outward-looking natural surveillance level of elementary schools by measuring the visibility levels of windows in three dimensions with omnidirectional panoramic images. However, this measurement method is not suitable for analyzing many targets because of the considerable amount of complicated data processing. The present paper proposes a new measurement method to efficiently analyze many schools and understand the trends of their natural surveillance level statistically.

References


