Sukwai *et al. Built Heritage* (2022) 6:23
https://doi.org/10.1186/s43238-022-00071-z

Built Heritage

RESEARCH ARTICLE

Open Access

Identifying visual sensitive areas: an evaluation of view corridors to support nature-culture heritage conservation in Chiang Mai historic city

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Abstract

The visual integrity of mountains contributing to cultural landscapes as nature-culture attributes is often obscured by the vertical intrusive built environment, especially in buffer areas of protected heritage zones. Therefore, this study argued that even low/medium-rise buildings that inappropriately appear in the horizontal visual plane could be a factor increasing sensitivity to this panoramic view.

An integrative tool – visual sensitivity assessment – consists of Viewshed and Skyline analysis considering the pedestrian's visual limitation in identifying the sensitive areas of the mountain view corridor in the historic city of Chiang Mai. The visible mountain areas (VMAs) were determined as a baseline, and their relationship with the visible building areas (VBAs) was then examined using statistical correlation to define a strong negative relationship as the visual sensitive areas in five zones. The results showed that the buffer zone was found to have more areas with visual sensitivity values, but this varies depending on the characteristics of buildings and the assessment from the view corridor. Meanwhile, in height-restricted areas, such as historic area zone 5, there are some concerns about the visual intrusion, which necessitates continuous monitoring using the assessment result as a guideline.

Incorporating the results into implementation could support cultural landscape conservation in Chiang Mai city. The method is applicable in historic cities with similar settings to produce the baseline for the built environment that is harmonious with the cultural and historical characteristics of the city and with respect to its broader setting.

Keywords: Nature-culture heritage conservation, Mountain view corridor, Visual sensitivity assessment, Intrusive built environment, Visual integrity

1 Introduction

The view of heritage in relation to a broader context reflects a city's distinctiveness and local character. The spatial coherence of composing elements together with the broader setting gives the city 'imageability' or a strong image that is important for the legible landscape (Lynch 1960). The special view that contributes to a city's significance, such as an important mountain seen from certain locations or between-building areas, makes a city memorable (Moggridge 2010). The continued preservation of landscapes and urban vistas has been highlighted in maintaining a property's Outstanding Universal Values. Cullen (1961) noted that ignoring the historical element of a city would limit its quality space production, despite the lack of scientific tools at the time (Cullen 1961). Since then, city heritage vista/view corridor regulations and/or practical guidance have been a source of concern, which should be evaluated at an early stage of building

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development (Bandarin and van Oers 2012, 181). The UNESCO has been concerned about the rise in disturbances to 'Visual Integrity' and held an expert meeting on this question in 2013. Nearly half of the state parties reported preservation issues around this topic (50 out of 120 state parties) (Seyedashrafi et al. 2021). In the report that was produced, these states voiced their concern and urged local authorities 'to integrate urban heritage values and their vulnerability status into a wider framework of city development.'

The continuous quality of heritage and the broader landscape make it difficult to maintain the rapid growth of urban areas where changes in land use and urban fabric can potentially affect site significance and integrity (UNESCO 2009). 'A major potential impact of development upon the historic urban landscape is visual' (Moggridge 2010, 66). This visual impact emerges in particular when intrusive buildings or uncontrolled development disrupt the skyline, affecting the relationship between historical heritage and the surrounding environment. The Xi'an Declaration emphasised that urban heritage sites and routes have been threatened by transformation processes and rapid changes and has sought quantifiable indicators to support land use that preserves significant skylines (ICOMOS 2005). Indeed, these areas need a novel management apparatus to balance new development with the cultural and historical characteristics of a city and with respect to the wider setting (Jokilehto 2010).

Visual impact assessment is recognised as a useful approach for protecting views that are significant to a city. It aids in determining the features that are important to a city's image and that should be protected as well as in identifying areas that are sensitive to the loss of authenticity and integrity. Visual impact assessment is grounded on the deteriorating effect an intrusion may have on the wholeness of a perceivable image. Gestalt psychology implies that what we see is interrelated with each other as well as with the observer. Empirical studies have shown that the relationship between foreground building structures and background mountainous vistas affects people's preferences and the ways in which they perceive the whole scene (Zacharias 1999; Stamps 2002). Based on the idea of figure-ground perception, we divide the ways in which people perceive the landscape as a whole into foreground and background, which rest on variation between visual elements (Wagemans et al. 2012; Metwally 2021). Landscape elements have different characteristics, which are often visually perceived as alienated from each other. For example, buildings are alienated from natural settings. Furthermore, different levels of disparity across landscape features (e.g., shape, size, colour, texture, etc.) lessens the sense of unity and contribute to the sense of discontinuity in patterns within a particular vista. Indeed, a landscape element may be visually dominant and attract more attention than others. Scale and arrangement are two factors that are involved. The location of landscape elements and distance from the observer affect the proportions of the visible area (Bell 2005). As a result, within the visual field, the spatial attributes and visible area of foreground buildings may influence the visible mountain background.

The relationship between the building foreground and mountain background has been investigated in studies concerning mountain scenic protection and development. An application of the Viewshed to define the area of interest with regard to human's visual field and to determine the visible mountain area as the background of a protected vista. Prior studies utilised the mountain's visible landscape as a baseline in prioritising protection in the advantage of foreground area zoning (Tong et al. 2016; Tara et al. 2020). However, these studies have mostly focused on determining future zoning for building height without considering the impacts of existing buildings. Other factors related to spatial attributes have been shown to influence visual sensitivity, such as location (Saeidi et al. 2019) and use (Yasumoto et al. 2011), and their positional relationships with each other (Fisher-Gewirtzman et al. 2005) may need to be investigated in mountainous cities. More research on the relationship between building silhouettes and mountain skylines in view should be conducted in actual cities (Stamps 2002). Further clarification on the morphological or visual aspects of these vistas is required in the context of historical and cultural urban heritage landscapes (Rey-Pérez and Pereira Roders 2020).

The application of the visual field in view impact assessment has been found in many cases in European cities. In London, for example, results were achieved through the use of photographic imagery in association with the visual field to develop measures to identify sensitive areas where the skyline may be affected by new buildings. In 2003, high-rise building projects in England affected the Tower of London, resulting in a heightened integrity risk for the site. In response, the London local authority conducted a visual impact study in 2009. The creation of view cones has been proposed to define visually sensitive zone from public locations to the important cultural landmarks while providing further control of the intrusion of buildings in the foreground, which may dominate the landmark within the protected view corridor. According to the study, the British authorities have issued national legislation and local regulations regarding the site's visual protection (Greater London Authority 2012; UNESCO 2006, 2012; Moggridge 2010). This approach has worked well in historic towns. However, there have been significant drawbacks when questioning evaluation methods that use photographic imagery for broad vistas and mountains views in the far distance since those may differ because they entail a broader view of the landscape than the view onto a landmark building. Moreover, lateral surfaces can affect the perception of silhouettes due to the limitation in focused vision. As a result, traditional photographic imagery may be insufficient (Moggridge 2010). In this case, 3D computer modelling can assign parameter values that are close to human perceptions and provide more realistic estimations that are required to study foreground features in far distant views (Stamps 2002; Fisher-Gewirtzman et al. 2005). The historic city of Vilnius, Lithuania is another good example. The city's historic urban landscape was harmed by the intrusion of unplanned high-rise buildings. Local authorities discovered a way to develop an impact assessment tool for urban management mechanisms by composing new building arrangements using a 3D GIS city model-based tool to assess the impact of these high-rise buildings. One recommendation made in the Vilnius case is '…to assess visual impact on the World heritage cities and to guide city planning upstream of development proposal- not after planning decisions have already been made…' (European Unions 2011, 7). The historic city created management mechanisms to preserve its panoramic views. Applying the 3D GIS tool to analyse large amounts of spatial data in the urban environment could diminish the impact of future development, offering a more realistic picture while undertaking visibility analysis and assisting in monitoring the effects of new construction on the city's historic landscape. Therefore, the tools developed in both cities have contributed to preserving visual integrity, which is necessary for the view of the urbanscape from certain places, as well as views of the distant landscape. Hence, there is room for distant views from certain arrival routes that are also important to maintaining property values and that need further investigation.

In Asia, there are concerns that the cultural landscape has faced several threats due to growing infrastructure development and urbanisation (Rössler and Lin 2018). In East and Southeast Asian cities, many mountains are home to cultural heritage sites. However, the increasing trend of urbanisation and population growth in mountain regions (Ehrlich et al. 2021) may put natural and cultural heritage sites at risk of losing significant value. It is, therefore, important to develop an impact assessment tool and management mechanism that provide adequate protection from adverse effects on the linkages between them.

Among several historical cities in Thailand, Chiang Mai is one of the most ancient settlements in the mountainous region. The city's distinctive settlement was developed by combining spiritual beliefs associated with the sacredness of mountains with ecological wisdom, such as Feng Shui ideology that is present in China and East Asian countries to protect mountains as natural resources and defence. Nevertheless, Chiang Mai city has a unique way of combining it with the animism beliefs of indigenous Tai and Lawa and the Hindu-Buddhist cosmology concept. As a result, the city's image is expressed through the unique landscape of the walled city settlement with the mountain that represents the centre of the universe (Monuments, sites and cultural landscape of Chiang Mai, capital of Lanna – UNESCO World Heritage Centre n.d.). The sacred mountain is visible from many vantage points in the city and is appreciated by visitors and local residents; moreover, numerous heritage sites are located in the area. Therefore, the city government has attempted to protect the features that contribute to the landscape's significant value by including the mountain area, the city wall, and the cultural route in various conservation projects, and in 2015, it attempted to make it to the World Heritage Tentative List as a mixed site (Chiang Mai Provincial Administrative Organization 2019). However, in the historic town located in the urban centre where built-up areas have encroached on the protection buffer (Setiawan and Rahmi 2002; Srivanit and Hokao 2012), the lack of consideration of cultural landscape conservation concepts in city planning and the use of an advanced tool to evaluate visual impact have led to difficulties in effective preservation.

In Thailand, urban heritage protection regulations are enacted primarily under the Urban Planning Act of 1975[1] (Amended in 2019) and partially enacted under the Enhancement and Conservation of National Environmental Quality Act of 1992[2] (Amended in 2018). Both are authorised by the central government, but they include channels for local authorities to propose areas to preserve under the law, as well as raise issues emerging out of the protection policies. The control of building height in the urban planning act can be declared at three levels: the provincial plan, the urban plan, and the specific plan (FAR, GAC direct height control area). The Urban Planning Act, in particular at level of the specific plan, determines the objective of the regulation in protecting or restoring cultural sites that contains aesthetic, architectural, and historical values, as well as those natural areas with aesthetic value (Urban Planning Act 2019, Section 40, Clause 3). The Conservation of the

[1] Urban Planning Act was issued in 2019. It can be retrieved from www.ratchakitcha.soc.go.th.

[2] The Office of Natural Resources and Environmental Policy and Planning (ONEP) is the local authority responsible for implementing regulations designated by the Thai central government. The National Environment Quality Act can be retrieved from www.ratchakitcha.soc.go.th.

National Environmental Quality Act focuses on a specific area that needs to be preserved due to its natural or aesthetic value or amenities. This act is intended to fill the gaps when the Urban Planning Act may be ineffective (National Environment Quality Act 2018, Section 43–45). In addition to these regulations, Thailand abides by its own Charter on Cultural Heritage Site Management, which can be found at ICOMOS Thailand. As a guideline for local Thai authorities, the charter clearly states that the cultural landscape should be preserved. It suggests local action to assess its impact as an essential part of preserving cultural value based on people's participation and scientific and managerial mechanisms (ICOMOS Thailand Charter 2011). In 2006, the urban vista of Rattanakosin Area in Bangkok was explored using the visualisation tool. The study proposed that computerised analysis could have been used to assess the threat of incoherent development to visual integrity (Sourachai 2006). A recent study found that cultural landscape conservation in Thailand is being gradually implemented, and guidelines have been offered to protect local cultural values. The findings recommended using tools, such as scientific and/or socioeconomic tools, in applying regulatory guidelines to local characteristics (Anurak and Dankittikul 2017; Bunchuduang 2019; Jhearmaneechotechai 2015; Piromreun 2004).

This study intends to provide scientific measurements for future development zoning in Chiang Mai's unique cultural landscape. We analysed the sensitivity of the observed location along the route that provides a mountain view corridor, using the vantage points from which the mountain is visible as a baseline and comparing them to areas with visible buildings. The finding discusses the optimal value from an existing building that adversely affects the landscape and the relationship between nature and culture and between mountain and urban heritage. The conclusion of our scientific analysis may provide some insights into heritage protection within the buffer zone in Chiang Mai city.

2 Methods

2.1 Study area

The study site is located in Chiang Mai, Thailand. Chiang Mai is a historic walled city that served as the former capital of the Lanna Kingdom for 725 years. The city was founded in a gorgeous site on the slopes of a sacred mountain called 'Doi Suthep,' which is located to the west of the city and slopes down to the east, where the walled city was meticulously planned to represent the territory of the sacred universe. The Doi Suthep has been revered as a sacred mountain by the people of Chiang Mai. It is regarded as a symbol of Mount Sumeru – the centre of the world that connects humanity and devas according to Hindu-Buddhist cosmology and as the location where ancestors' spirits reside according to indigenous Tai and Lawa animism beliefs (Sodabunlu 2003). As a symbol of the mountain's holiness, the most prominent temple – Phra That Doi Suthep – was built on top of the mountain in 1419 AD and houses relics of Buddha. Later, the notable Lanna-style temple, Sri Soda temple, Fai Hin temple, and Pha Lad temple, were built in descending order along the trail to the top of the mountain to symbolise the four stages of enlightenment (Wonglanka and Han 2020, 32). The mountain is still an important pilgrimage destination and spiritual symbol for the Lanna people, as well as a gorgeous tourist attraction that helps the local economy. The old city, framed by nearly square-shaped walls of approximately 2.5 km^2 encircled by moats, is located approximately 3 km east of the foothill. Suthep Road connects the old city wall and the mountain, which was historically established to assist monarchs commuting to enjoy their stay at a scenic palace – Wieng Suandok outside the city wall and as a link to the pilgrimage path to Phra That Doi Suthep. Suthep Road is in the city's development zone. It is located on the same plane as the main urban axis known as Rachadamnoen road, which is located in the historic conservation zone, making the two roads a wonderful place to view the panorama of the old city with the sacred mountain (see Fig. 1).

The Doi Suthep mountain, the city wall area, the two routes leading directly to the mountain – Suthep and Rachadamnoen roads – and their surroundings are all included in this study for which the boundaries are determined based on road borders and land-use designated zones. The buildings in the study area are identified as obstacles, while the Doi Suthep mountain is identified as the target view. The mountain rises approximately 1658 m above sea level and has a total area of 165.605 km^2 on the east side, which can be seen from several locations in the city and from the road. Because of the historical significance of the mountain and the old city, the roadways are chosen as observation locations for the study. The roads are approximately 3 and 1.2 km long, with widths of 16.45 and 9 m, respectively (see Fig. 2). Furthermore, because visibility can be influenced by view angles and distance, the study area is separated into five zones to ensure accurate analysis. On Suthep Road, three zones located in the buffer area connecting the historic city and the mountain are bounded by Kanklong-Cholprathan Road in Zone 1, Siri Mangkalajarn Road in Zone 2, and the west side of the city wall in Zone 3. Furthermore, two zones on Rachadamnoen Road, located within the city wall and moats, are bounded by Prapokkloa road in Zone 4 and the east side of the city wall in Zone 5.

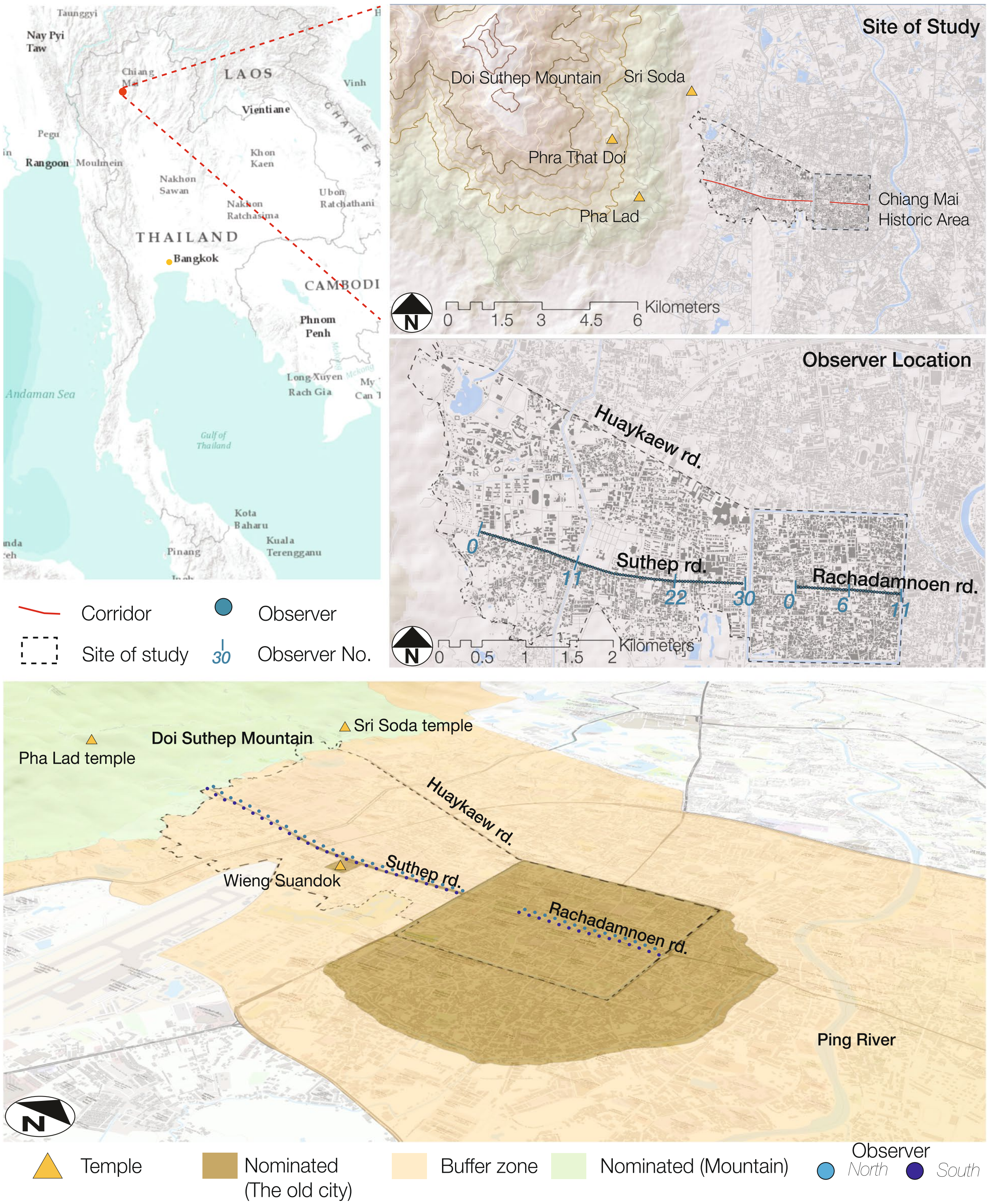

Fig. 1 Site study (Source: the authors)

Fig. 2 View from Rachadamnoen and Suthep road to Doi Suthep Mountain (Source: the authors)

2.2 Viewpoint location

The viewpoint is the essential factor that needs to be determined before conducting the visibility analysis. To ensure accurate measurement of visible areas with different characteristics, the observer's location and activity mode should be determined when the value input for the field of vision parameter is added.

The distance between the viewpoint location and the height of the eye level is determined by the mode of human activity in the environment. Because this research focuses on measuring the area of the mountain and buildings that can be seen by the observer along the roads, we assume that the observer is walking, so that the viewpoints are placed in the direction of movement facing the mountain as serrated locations along the north and south of the roads to simulate a pedestrian walking on the footpath. The distance between viewpoints is approximately 90 m, which is the average distance walked by an adult per minute (Forde and Daniel 2021; Murtagh et al. 2021), and the height of each viewpoint is set at 1.6 m above ground level to accommodate the average level of human eyes. The north and south sides are evaluated. Subsequently, critical similarities and differences are discussed through statistical analysis.

2.3 The creation of the view cone

The view cone was created based on the human visual field and the perception of different visual elements. The visual limitation was the input value that must be entered into the parameter for the computation of the visible area and the formation of the view cone. The visual limitation determined the values for the maximum line of sight and visual angle depending on the context so that the values assigned differed when measuring two different aspects.

The maximum line of sight is defined by the maximum distance visible to the observer that can affect the proportion of the visible areas. It may be limited by human vision as well as by landscape elements that obscure the view. Mountains can be visible from various distances depending on the elevation surface and the visual service radius (Lee et al. 2019; Schirpke et al. 2013). In this study, the maximum distance for measuring the visible mountain area was established at 11 km; depending on the distance between the farthest viewpoint and the top of the mountain, it covers all visible areas. The visible distance can be limited by buildings in a dense urban region where there are many physical structures. This study aimed to investigate the urban setting. We established a distance of 500 m from the viewpoint because there was no significant difference in visibility when determining the sight line with 500 or 1000 m (Yu et al. 2007). Therefore, this value is appropriate as a maximum distance to study urban areas (Yasumoto et al. 2011; Park et al. 2017). As a result, the viewpoints included in each zone were not precisely positioned within the zone's boundaries but were considered in terms of sight line distance. As a result, some viewpoints may fall within the boundaries of the following zone.

Based on human perception and a binocular field of view, we set the value of the visual field at 124 degrees (Panero and Zelnik 1979). Furthermore, Tara et al. (2021) suggested that a viewing angle of 124 degrees, with 60 degrees in the centre, is appropriate for investigating the human perceptibility of the built environment, especially in terms of its height relationship (Tara et al. 2021). The total value of 124 degrees was used to generate the view cone in this study. The centre visual field was separated into 30 due to the road centre and to increase accuracy in executing the area calculation. A view cone was assigned to each viewpoint. Each view cone had four sections that formed the border for the evaluation and calculation of visible building areas. As shown in Fig. 3, Sections L2, L1, R1, and R2 were determined.

2.4 Measurement of the visible mountain areas and visible building areas

To investigate the relationship between building foreground and mountain background, the analysis in this study was divided into two parts utilising Viewshed and Skyline analysis in ArcGIS 2.7. The viewshed was used in the first phase to calculate the visible mountain area (hereafter, VMA). In general, the viewshed is a raster-based visibility analysis tool that is used to distinguish between visible and invisible surface areas from a specified location.

Studies on the visibility of landscape scenery of high topographical places such as hills and mountains used the viewshed accompanying a digital elevation model (DEM) or a digital surface model (DSM) and land cover/land use data to assess scenery value in visible areas of the natural and built environment. This research aims to determine the visible surface of the target mountain, which may change due to obscuring elements such as vegetation or buildings. Therefore, buildings are permanent modular structures that require specific modification regulations. Hence, we focused on this aspect and excluded temporary structures such as signboards and vegetation from the analysis. To input the parameters for the study, surface elevation raster and viewpoint data (locations, height, and field of view) were needed. The digital elevation model (DEM) with a resolution of 30 m × 30 m from NASA's EARTHDATA (NASA n.d.) was employed for this research. The original DEM data, however, do not include building data, such as heights or locations that can obstruct the view. As a result, the surface map was created by combining the building data with the ground elevation (DEM). The building dataset was constructed with actual heights and positions in the study area. However, when combining the different datasets, we must set a cell size to match the existing input raster dataset. In this study, we used a DEM with a raster cell size of 30 m, which may not be compatible with the size of the actual building footprint. Therefore, some raster cells on the road generated increasing elevation values. In this case, we excluded the viewpoints located in those areas to avoid any analytical bias. Finally, the visible mountain area was computed in square kilometres (km^2), as indicated by the output surface raster of the mountain area from the viewshed analysis.

The visible building area (hereafter, VBA) was measured in the second stage. During this phase, Skyline analysis was performed, which can generate silhouettes based on building forms extracted from the open sky. From a specific viewpoint, the skyline can measure visible ratios between building areas and the sky. It has been used to calculate the visible sky to detect the effect on the outdoor environment, such as urban climate and temperature (Park et al. 2017), while a recent study extended its use to investigate changes in urban scenes based on the total area of visible buildings (Tara et al. 2021). The visible building areas were measured as a complete area

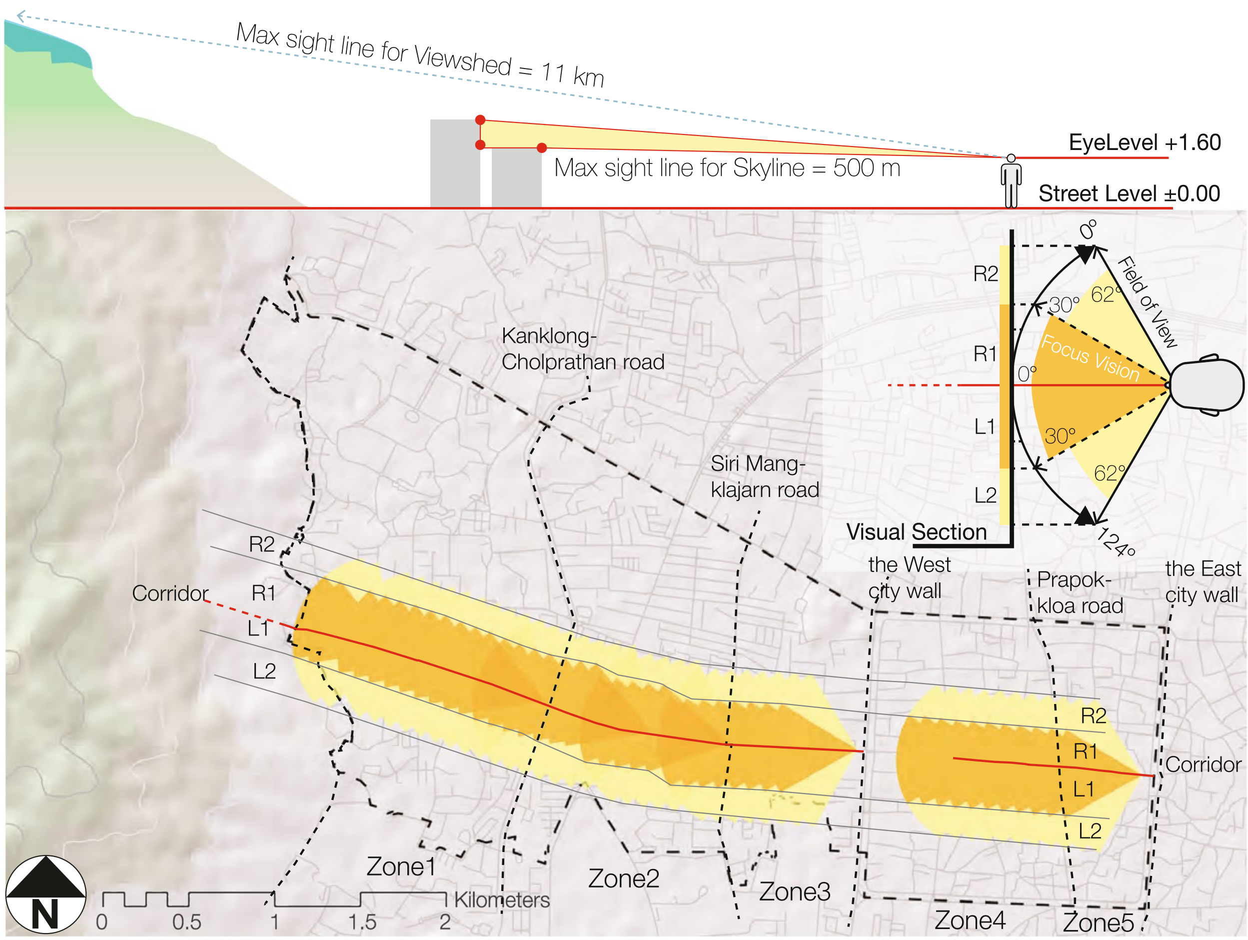

Fig. 3 Determination of zones and visual field sections (Source: the authors)

inside the visual field. To identify the sensitive sections of the panoramic mountain view corridor, however, it may be necessary to measure in a sectional horizontal plane, which would be more appropriate for the view type.

The skyline function in ArcGIS 2.7 was used to compute the visible area of buildings. The skyline is generated by using data from buildings and viewpoint features as input for 3D analysis. Using the skyline graph tool, the output may be shown as a graph containing the horizontal and vertical angles travelling from the viewpoint to each of the vertices on the skyline. In general, the tool may define the skyline surrounding the observer at a total horizontal view angle of 360 degrees. Therefore, Tara et al. (2021) proposed unwrapping the skyline graph and selecting a horizontal field of view of 124 degrees to determine the total visible building areas. The benefits of utilising this method include a data display that is close to human perception and the ability to select various visual angles for calculation. For the calculation, this study determined a total field of view of 124 degrees. Furthermore, it was separated into smaller visual fields to determine the areas shown in the unwrapped graph. The trapezoidal rule was utilised to calculate the estimated area under the curve (AUC) in trapezoid forms. The formula is shown below.

$$\sum_{i=1}^{n}\left(\frac{VA_i + VA_{i+1}}{2}\right)(HA_{i+1} - HA_i)$$

where VA is the vertical angle (y) and HA is the horizontal angle (x).

The trapezoid calculation area offers each viewpoint's visible building areas in each section based on the selected horizontal and vertical angles. Due to the limitations in the visual angle determination, which may result in underestimated results, the visible building area in this study was assigned in square units (unit 2). Then, the results were used for further statistical analysis (see Figs. 4 and 5).

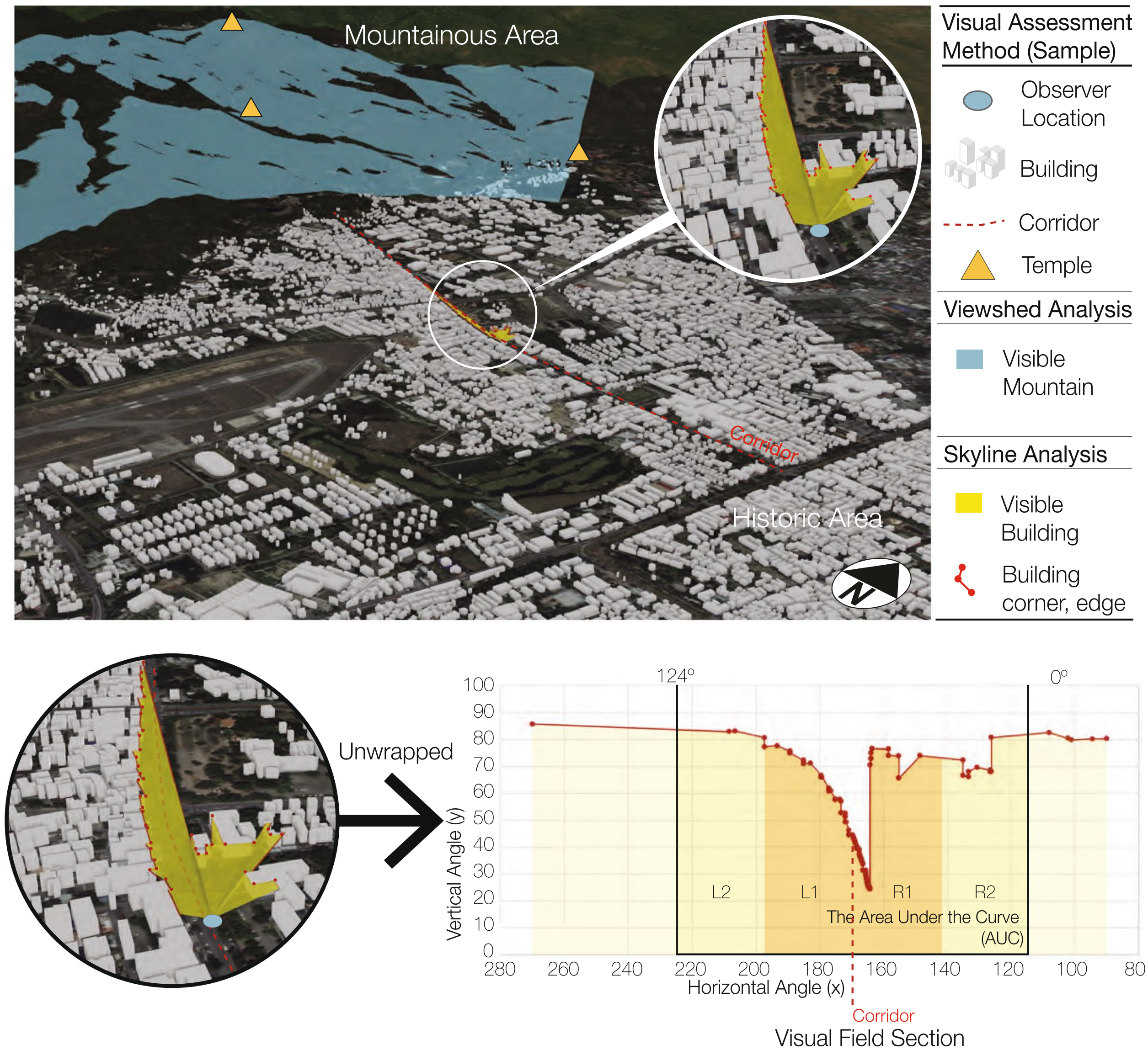

Fig. 4 Example of visible area measurement (Source: the authors)

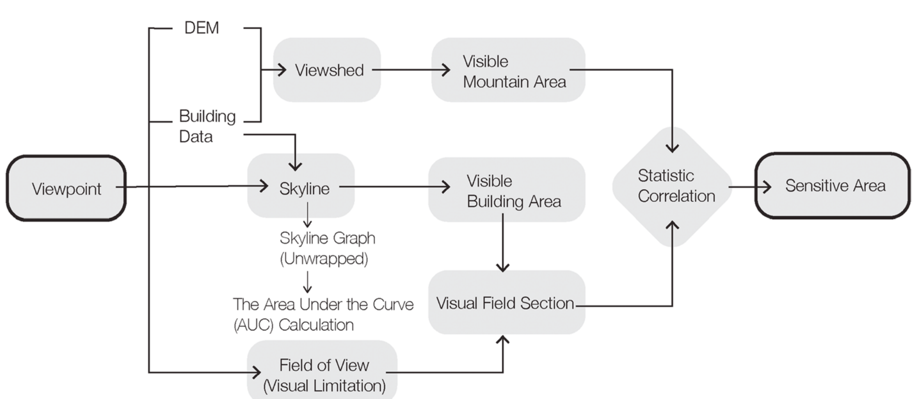

Fig. 5 Research Methodology (Source: the authors)

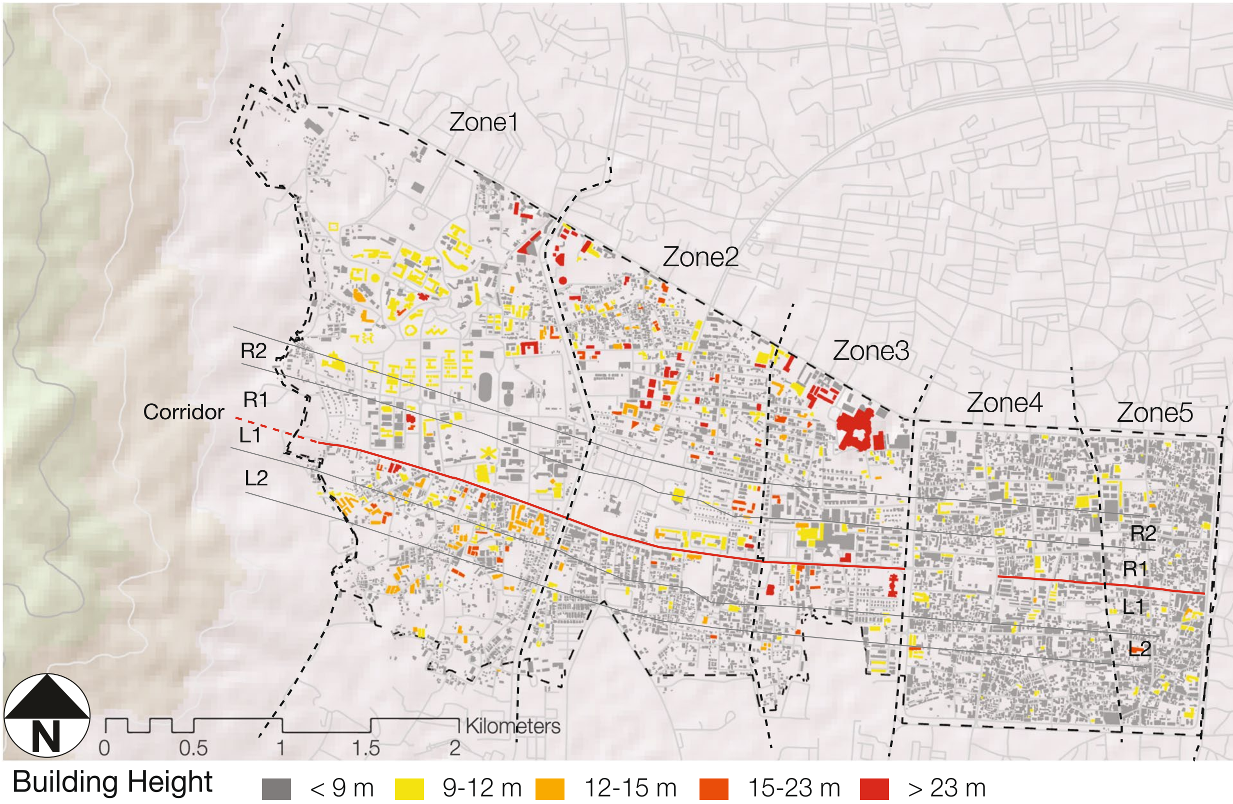

Fig. 6 Building heights in five zones (Source: the authors)

2.5 Building and zone characteristics

There were 9047 buildings in the study area. Building heights varied, ranging from low buildings with heights of less than 12 m to heights greater than 23 m. In Thailand, according to building control acts[3] and zoning ordinances,[4] the height of low buildings is determined to be 12 m, while a medium-high building is 15 m, and buildings taller than 23 m are considered large-tall buildings. In the study area, buildings taller than 15 m were mostly located near the road, which are more common in places near the mountain than within the city walls due to building height regulations in the historic zone (Zones 4–5) (see Fig. 6).

In terms of building density, clusters of buildings were dispersed throughout the city, providing high density to specific regions, particularly on the left side of Suthep Road, in the north of Zone 2 near the road, and on all sides of the city wall. The areas around Suthep Road and some parts of Zone 2 were projected to have high ground coverage in terms of building coverage ratio. Furthermore, it is substantially higher in the northern half of Zone 3 and within the city wall region (see Fig. 7).

The building use and coverage ratio in each zone reflect the features of that zone. Aside from residential building use, which was the most populated in all zones, the following building use and coverage ratio showed significantly distinguished characteristics (see Figs. 8 and 9). The proportions in the different uses of the buildings in each of the zones is described below.

- Zone 1 had the largest proportional residential use, which was mostly located on the L zone side, followed by education use, which was mostly on the R zone side.
- Zone 2 had residential, mixed use, and commercial use as the three most common proportional uses. It had a similar proportion in both zone sides. However, the R zone side had more proportional uses of open spaces and education use than the L zone side.
- Zone 3 had the largest proportional use for residential, followed by facilities and commercial uses, which were mostly located on the R side.
- Zone 4 had the largest proportional uses for residential, mixed use, and education/religious buildings.

[3] Building Control Acts no. 55 was issued in 2000. It can be retrieved from www.dpt.go.th.

[4] Zoning ordinance was assigned in the Chiang Mai's comprehensive land use plan in 2012. It can be retrieved from www.dpt.go.th.

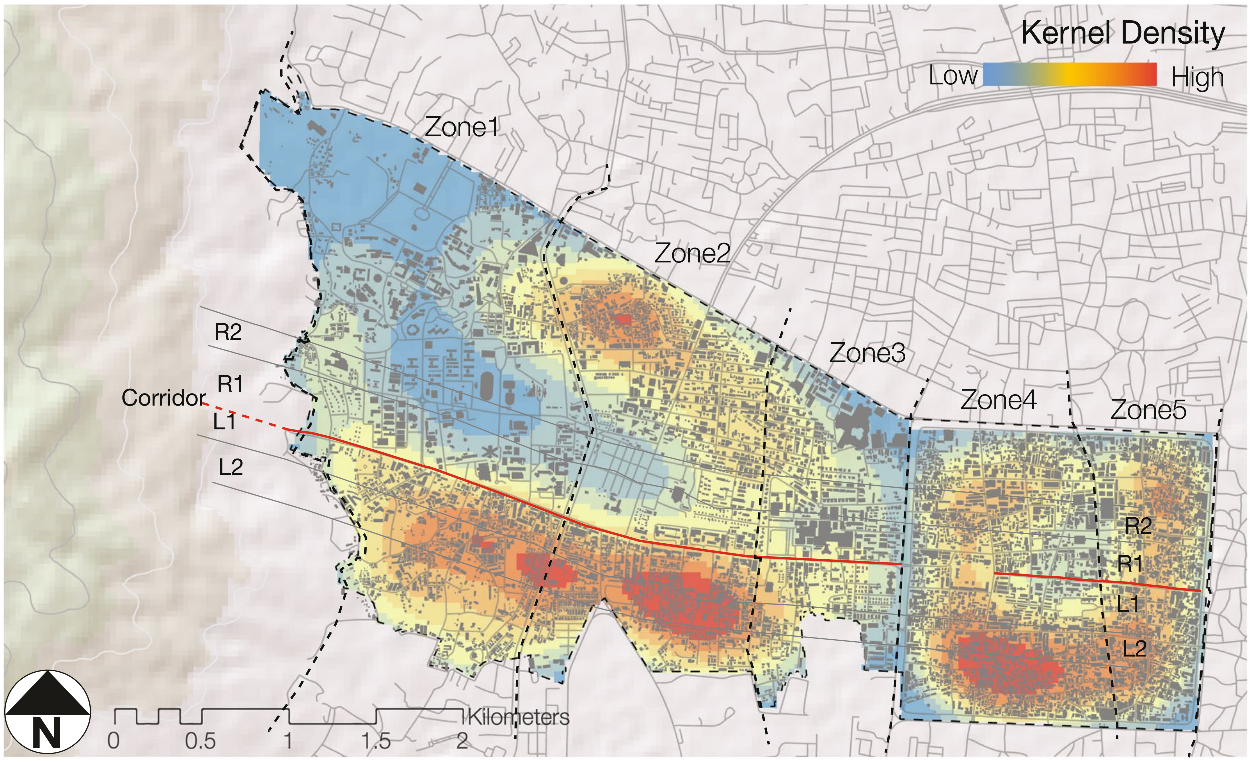

Fig. 7 Building density in five zones (Source: the authors)

– Zone 5 had the largest proportional uses for residential, mixed use, and commercial use.

All characteristics were conceptualised and summarised through building attributes according to their zones, as shown in Table 1.

3 Results and discussion

Statistical analysis was performed. First, descriptive statistics were used to determine differences between visible mountain areas (VMAs) and visible building areas (VBAs) in the five zones, as well as high and low visible areas, including locations. Second, correlation statistics between the VMA and the VBA in each zone were examined to identify sensitive areas.

3.1 Visible mountain and building areas

According to the results shown in Table 2, the average VMAs in Zones 1 to 3 on the north side of Suthep Road were 7.341 km^2, 8.989 km^2, and 6.115 km^2, and the average VBAs were 8426 $unit^2$, 8502 $unit^2$, and 8055 $unit^2$, respectively. The average VMAs in the south were 6.850 km^2, 9.857 km^2, and 7.724 km^2, and the average VBAs were 7725 $unit^2$, 7938 $unit^2$, and 8709 $unit^2$, respectively. Zone 2 had the most VMAs, whereas Zone 3 had the fewest VMAs in the north and the most VBAs in the south. Zone 1 had the fewest VBAs in the south. On Rachadamnoen Road (Zones 4 and 5), the average values of the VMA in the north of the two zones were 12.144 km^2 and 14.487 km^2, and the average values of the VBA were 9368 $unit^2$ and 9642 $unit^2$. The average VMAs in the south were 14.320 km^2 and 13.194 km^2, and the average VBAs were 9501 $unit^2$ and 10,261 $unit^2$, respectively. Zone 5 had the most VMAs in the north and VBAs in the south. Zone 4 had the fewest VMAs and VBAs in the north.

3.2 Statistical analysis

To identify sensitive areas, it is necessary to examine the relationship between variables. Based on the VMAs and the VBAs of each viewpoint, Pearson correlation analysis was conducted to explore the relationship between variables. The visible mountain areas were entered as a dependent variable, while the visible building areas of each section were used as an independent variable. To comply with the assumption test for Pearson's correlation, this study validated the data shown in Table 2. VMAs and VBAs were produced from identical observer locations, which were determined through systematic selection in the site study. Thus, the variables were randomised independent variables with continuous paired

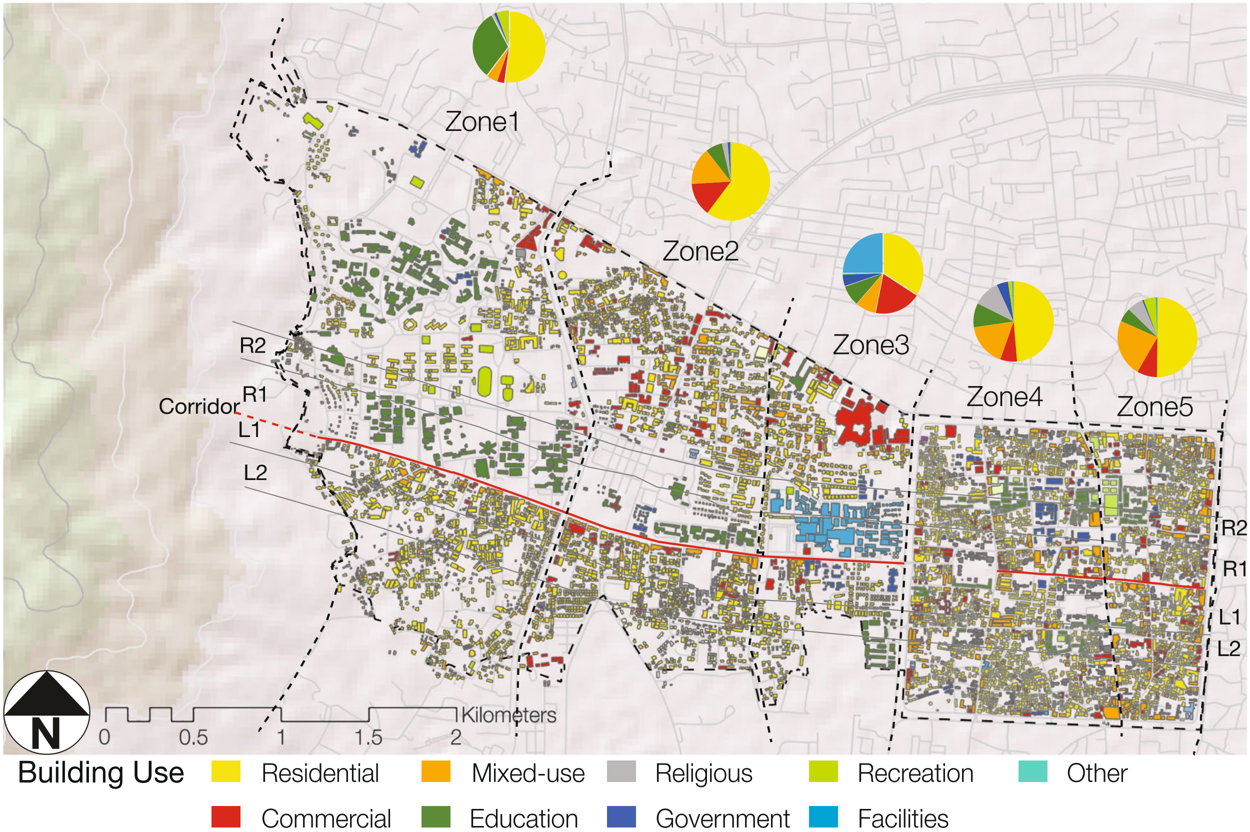

Fig. 8 Building uses in five zones (Source: the authors)

attributes. The variables showed significant normality in their distribution, with slight skewness, which was identified by histogram and normality q-q plot (see Fig. 10). The final assumption was the association with a linear relationship and the scatter plot for the VMAs and VBAs. The scatter plot showed a cluster of variables along the trend line and was unable to respond with a nonlinear trend. The correlation analysis in this study implied the strength of the relationship in correlation as the qualitative of the sensitive value, which further represents the ratio of sensitive areas (by their zoning of Section L2-R2). Moreover, the direction of the relation responded to the possibility of a negative or positive degree of relation between the VMAs and the VBAs.

The association between the VMAs and the VBAs in each of the two road zones is shown in Table 3. The Suthep Road investigation revealed that the VBAs in Sections R2-R1 and L1 in Zone 2 (north) and R2-R1 in Zone 3 (both north and south) had a strong negative correlation with the VMAs. Zone 1 had a moderately negative correlation in Section R2. For Rachadamnoen Road, a strong positive correlation between the VMAs and the VBAs was found in almost all sections of Zone 4, except R2 (south). Surprisingly, Zone 5, the adjacent area, exhibited a considerable negative correlation between the VBAs of R1, L1 (north) and the VMAs.

According to the VMA results, Zones 4 and 5, where the old town is located, had the highest VMA average compared to Zones 1–3, which allowed for new development growth. The VMA value was less than half of its average (Zone 5 at 14.487 compared to Zone 3 at 6.115). The building height regulation (limit at 12 m) in the historic town highly affected the VMA even though the VBAs of Zones 4 and 5 were greater than those of Zones 1–3 (see Fig. 6). The VBA in the historic district may be influenced by the narrowness of the historic streets, particularly in Zone 5, where the building coverage percentage was the highest (see Fig. 9). Historic regions are generally used as residential and/or mixed-use areas.

Zone 1 had the lowest VBA average due to its low building density and the lowest BCR. Its proximity to the mountain may be related to the VMA. The key elements in this zone were educational institutions and their surroundings. Educational institutions were located in Zones R1-R2, while residential areas, mostly for student dormitories, are located in Zones L1-L2. Despite having the most observers ($n = 22$), the VMA

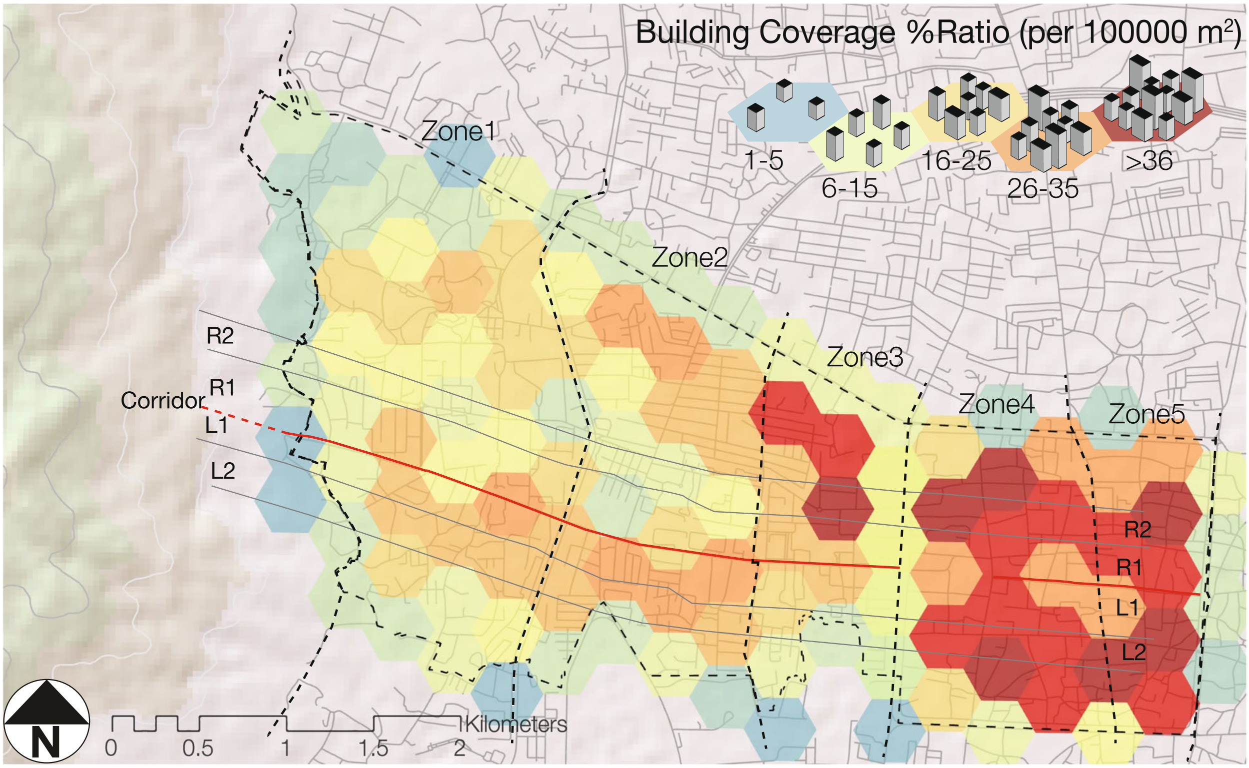

Fig. 9 Building coverage ratio in five zone (Source: the authors)

Table 1 Building use, height, coverage, and coverage ratio in the five zones

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Building use[a](1st-5th)	Res 51.8%	Res 61.1%	Res 34.5%	Res 50.6%	Res 52.1%
	Edu 32.3%	Mix 15.6%	Fac 25.4%	Mix 18.0%	Mix 24.2%
	Rec 5.7%	Com 13.7%	Com 19.1%	Edu 10.1%	Com 8.4%
	Mix 4.7%	Edu 6.9%	Mix 8.3%	Reg 8.8%	Edu 5.8%
	Com 3.3%	Reg 1.6%	Edu 7.7%	Com 7.0%	Reg 5.1%
Min/Avg/Max Building Height (m)	3/5.7/30	3/5.8/45	3/6.4/45	3/5.1/18	3/5.3/21
Building Coverage (m^2)	638,097	504,415	336,781	592,721	346,089
BCR (per 100000m^2)	14.8	19.6	22.6	33.4	36.6

[a] *Res* Residential, *Com* Commercial, *Mix* Mix-use, *Edu* Education, *Reg* Religious, *Gov* Government, *Rec* Recreation, *Fac* Facilities

remained high and had the lowest standard deviation, indicating that the value distribution was lower than in other zones.

Zone 2 had the highest VMA and high VBA averages. This zone features the largest open space and the fewest buildings, particularly in R1-R2. Similar to Zone 1, Zone 2 was still considered instructional. The open space in R1-R2 had a significant relation to the VMA of this zone, which has the highest VMA in the developed area. It did, however, have the greatest VBA. However, according to the density map, the high density was concentrated mostly on the L1-L2 axis (see Fig. 7).

The SD showed the lowest VMA and value distribution in the VBA in Zone 3. The low VBA SD could be attributed to the fact that the density is the same on both sides of the street corridor. Medical facilities were positioned between R1 and R2, where mid-rise buildings were clustered (see Fig. 8). This zone allowed the facilities and their density to grow as the role of medical facilities expanded over time. Zone 3 showed a unique VBA representation that correlated strongly with the VMA value. In the L2 to R2 range, buildings could fully develop in terms of horizontal and vertical density, as well as height. Zone 3 had large minimum and maximum VMA values of 0.140 km^2

Table 2 Results of the visible mountain areas and visible building areas in each zone

Zone	Side of Street	Visible Mountain Areas (VMAs) (km^2)				Visible Building Areas (VBAs) ($unit^2$)			
		Avg.	SD.	Min.	Max.	Avg.	SD.	Min.	Max.
1	North ($n=11$)	7.341	1.700	4.275	9.697	8426	888	6936	9749
	South ($n=11$)	6.850	1.472	4.419	8.739	7725	677	6807	8668
2	North ($n=11$)	8.989	2.200	6.344	12.218	8502	1275	6730	9953
	South ($n=9$)	9.857	2.555	5.594	13.669	7938	882	6001	8789
3	North ($n=6$)	6.115	5.217	0.882	12.943	8055	540	7078	8492
	South ($n=8$)	7.724	6.421	0.140	16.996	8709	469	8051	9277
4	North ($n=6$)	12.144	6.403	1.751	21.906	9368	593	8600	10,031
	South ($n=5$)	14.320	5.112	6.947	19.469	9501	656	8774	10,336
5	North ($n=3$)	14.487	2.622	12.542	17.469	9642	209	9400	9770
	South ($n=4$)	13.194	5.911	5.539	18.372	10,261	394	9677	10,525

n number of viewpoints

and 16.996 km^2, respectively. Based on the SD, these numbers showed that there was a considerable degree of inconsistency in the mountain visibility in this zone.

The VMA average was extremely high in the historical area of Zone 4. Zone 4 also had a high VMA maximum value and strong connectivity to the mountains, despite having a greater VBA than the developed zones. The narrow streets in the historical district may result in a high VBA value. The highest maximum and distribution of VMAs resulted from low density in Zone 4, notably in L1-R1. Moreover, there were public open spaces, such as temples and small squares.

Zone 5 was similar to Zone 4. At 14.487 km^2, it had the highest VMA average despite having the highest VBA average. Its high density and BCR in all view sections (L2-R2) could account for its highest VBA (see Figs. 7 and 9). However, as noted in the overview, both Zones 4 and 5 are historical areas where building height has been restricted. The efficiency of height regulation to prevent visual intrusion is sufficient, according to VMA and VBA data.

3.3 Sensitive areas assessment

The sensitive areas in this study can be demonstrated through the results indicated by the strong negative correlation between VMAs and VBAs. In this study, it was found that each zone had different areas of sensitivity, perhaps due to the different aspects that were considered in the zones on the north or south sides of the street.

In each zone, the sensitivity was different on the north and south side of the street, as illustrated in Fig. 11. In Zones 1 and 3, the sensitivity in the northern section appeared to be similar to that of the southern section, but it was more severe in Zones 2 and 5. The severity in the north was probably due to the observers being closer to those structures that were located in the same direction as the viewing target, resulting in more obstruction in visibility.

The distance and viewing angles between the observers' location and the target view could affect the visibility of the target mountain. As a result, they contributed to sensitivity in specific areas, particularly in the close-range zone. The results in Zone 1 on both the north and south sides of the street revealed that sensitivity occurred in the areas (R2) despite these areas having lower building heights, density levels, and BCR than the opposite site. However, at the study's farthest zone – Zone 5 – sensitivity in the core area was observed north of the street.

Building locations and footprints seemed to have a greater influence on the visibility of the viewing locations in the zones that were farthest away. For example, the north street in Zone 5 exhibited sensitivity in the centre region (L1 and R1), which was the area with high density and BCR, while Zone 3 had significant BCR in its sensitive zones (R1 and R2). In contrast, no sensitivity was detected in the area with high density and BCR in Zone 1 (L1 and L2). The VBA and VMA results in Zone 2 showed a strong negative correlation in L1-R2 for the north street due to its density and BCR, while Zone 4 included no sensitive area.

Bases on the influence of its buildings (VBA), the sensitive region indicated the importance of its visual connection with the mountain. Although a university was located in the R1-R2 range of Zone 1, which indicated a significant association, that area was extremely visually vulnerable to new buildings or new development. Therefore, it should retain its existing level of BCR to safeguard the view corridor.

Despite moderate and weak sensitivity values in Zone 2, that zone may allow for certain low-density mid-rise

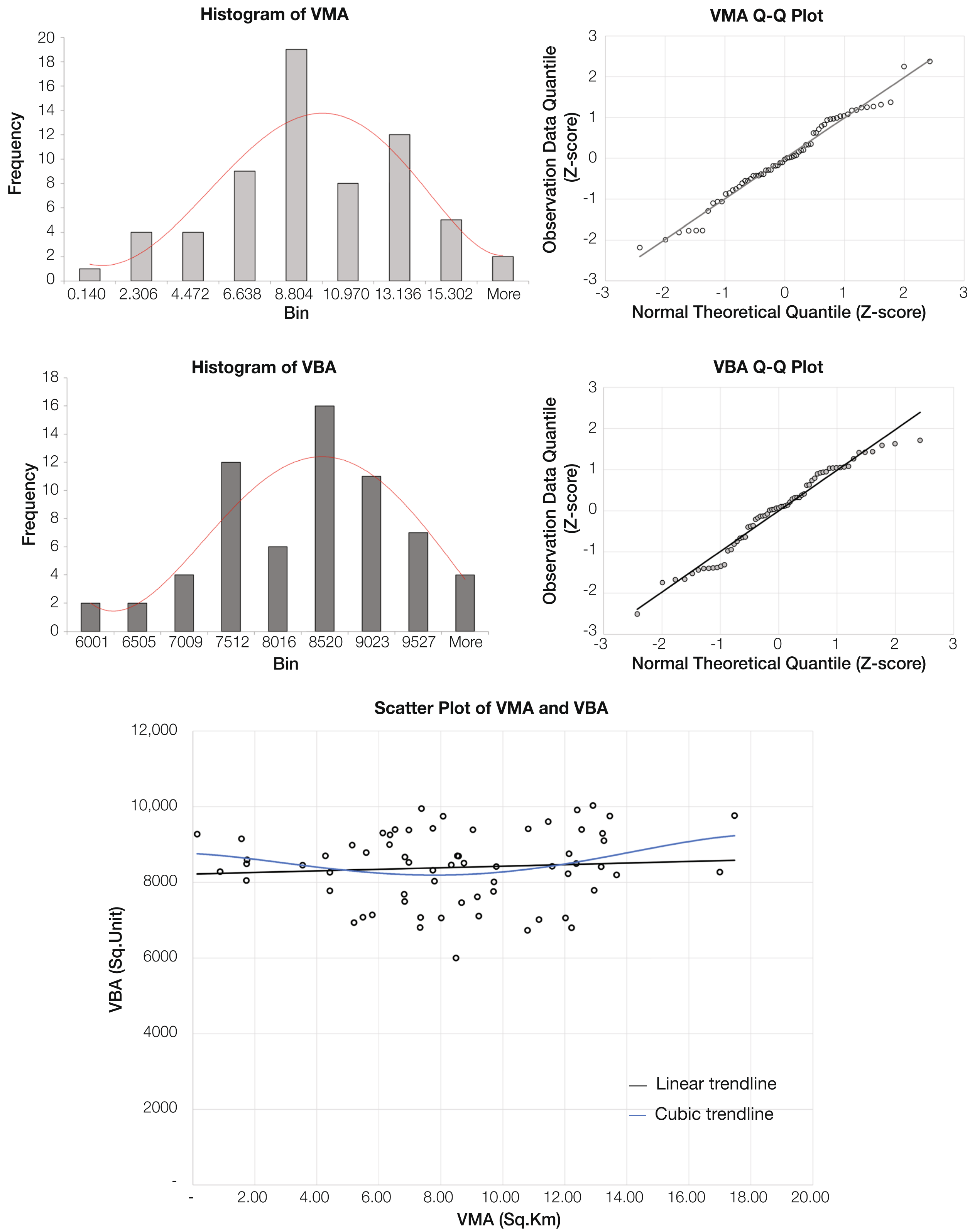

Fig. 10 Assumption in statistics for Pearson Correlation (Source: the authors)

Table 3 Correlations between the visible mountain areas and visible building areas

VBA	Side of Street	Zone				
		1	2	3	4	5
R2	North	−0.38[b]	−0.75[c]	− 0.70[c]	0.53[c]	1.00[c]
	South	−0.36[b]	0.04	−0.73[c]	−0.15[a]	0.45[b]
R1	North	0.04	−0.70[c]	−0.61[c]	0.64[c]	−0.73[c]
	South	0.02	−0.12[a]	−0.57[c]	0.52[c]	−0.01
L1	North	0.17[a]	−0.61[c]	0.30[b]	0.50[c]	−1.00[c]
	South	0.13[a]	−0.09	0.30[b]	0.57[c]	0.18[a]
L2	North	0.05	−0.12[a]	0.19[a]	0.68[c]	0.56[c]
	South	−0.23[a]	0.33[b]	0.42[b]	0.91[c]	0.59[c]

Coefficient = [a]Weak 0.1-0.3, [b]Moderate 0.3-0.5, [c]Strong 0.5-1.0

buildings to fill in, but the severity of the change/impact on the view corridor should be considered. Zone 3 had the greatest sensitivity along the view corridor, especially in R1-R2 of both the north and south sides of the street, where high and dense medical facilities had an adversarial impact on the view corridor, as evidenced by the strongest negative correlation in the sensitive area. The modification of BCR may not occur in Zones 4 and 5, the historic districts that have restricted construction heights, because these zones included religious spaces where open space is generally essential. Zone 5 was characterised by modern buildings that intruded into the historic district, leading to a high BCR in that zone. Due to its significant adversarial influence on visual sensitivity, notably from R1 and R2 for the north street, Zone 5 may demand strict monitoring.

4 Conclusion

The results represented in this paper identified specific areas to protect the visual integrity of the mountain, which contributes to the integrity of the cultural landscape in Chiang Mai's historic city. Future development and landscape conservation in the city must focus on these specific areas to consider the visibility of the mountain. For example, the areas between the target viewing zone and the corridor may need stricter controls for the closer zones, while the zones farther away should focus on the centre of the view cone.

The findings can be used to determine optimal values for coherent development that does not compromise visual integrity. The VMAs and VBAs in each zone can help define a critical vista control by using 3D modelling and then incorporating statistics. This study showed that Viewshed analysis, as a tool for constructing quality control in visual resources, is an appropriate measure to mitigate the adversary visual impact stemming from development with optimum/reasonable intensity of control rather than zoning ordinance covering a whole area. Determining the view corridor makes it possible to implement some development (Sourachai 2006; UNESCO 2013). Although city planning has recommended enacting height control in the area under study, FAR, BCR, and OSR, as drafted by Chiang Mai's comprehensive land use plan in 2021 by the Department of Public Works and Town and Country Planning (Thailand), would allow Chiang Mai to enact the Specific Plan and/or national environmental quality act (ICOMOS Thailand Charter 2011; Jhearmaneechotechai 2015; ONEP Thailand 2011). Scientific evidence that supports visual impact assessment (VIA) in the buffer zone could shed light on existing conflicts and change the tolerance levels in the cultural landscape. As discussed in the results, it is preferrable to implement intense controls in Zones 2, 3, and 5 of the view corridor.

Various parameters influencing sensitivity were examined. This study proposed looking into the components in a specific distance zone. The factors contributing to sensitivity in the near distance zone were distance and viewing angle, whereas spatial attributions of buildings, such as density and coverage ratio, should be considered in the farther zones. Medium/high-rise objects, particularly those close to the view corridor, may have an impact on the visibility of the mountain landscape. As observed during the study, most of the buildings within the sensitive region of the old city wall were not particularly tall. The analysis showed that the current building height control provides enough protection for the area. It cannot, however, be ignored because the number of tall buildings may increase sensitivity and cause visual inconsistencies in dense regions, particularly in the development zone. This study also examined building uses and heights. We found that specific building uses were associated with low density, which may lead to less sensitivity in the zone. As a result, additional studies using other scenarios

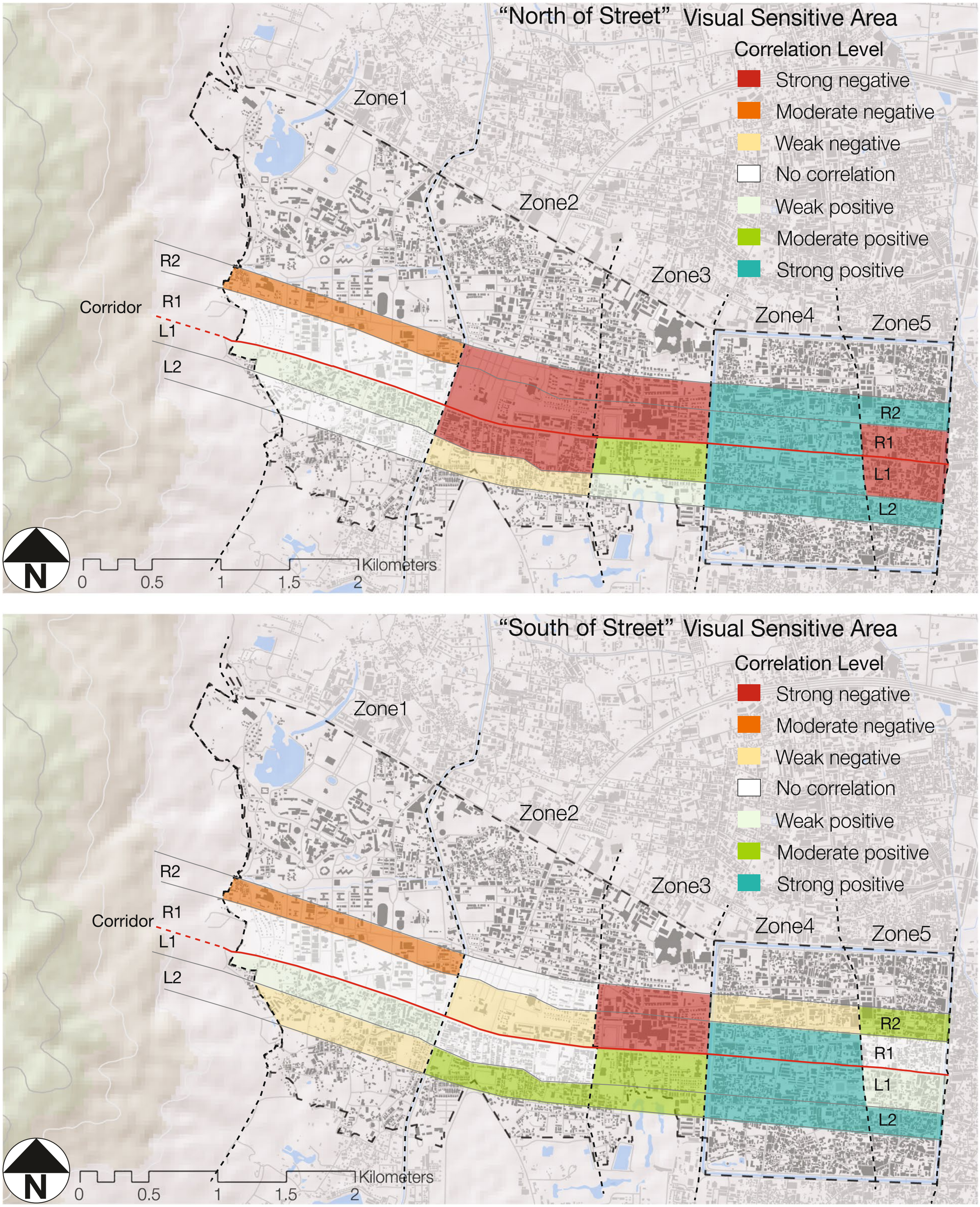

Fig. 11 Sensitive area in the north and south street of each zone (Source: the authors)

would help to thoroughly explain the influences of these components.

To explain how low visibility may be affected by the development area, control and more variables must be included to expand the framework. Furthermore, it would be ideal to update the data for an evaluation that is suitable for future development in the city and to challenge our results. Moreover, to create a high-quality pedestrian-focused view corridor, a qualitative analysis to determine the level of change that occurs when building height controls and/or pre-visual assessments prior to construction are combined with municipal regulations in specific plans under Thailand's national urban planning act. Our study makes it possible to regulate resources from the natural environment according to their location and to preserve their aesthetic, architectural, and historical value. In our study, the intensity level was ranked in descending order to reduce visual impact while remaining consistent with the socioeconomic level of the city.

In this study, 3D computer modelling was demonstrated as a possible advantage in using a view cone for horizontal visual analysis. Previous analyses have used viewshed in locations with various topographic levels and fewer buildings, but they were integrated with skyline analysis, taking visual limitations into account to evaluate the mountain landscape in historic urban settings. As a result, the method improves knowledge of the relationship between two distinct visible landscapes through quantifiable evaluation. Moreover, the DEM showing a deficit resolution, it may provide inaccurate raster calculations in this study. The utilisation of DEMs with higher resolution is needed in future research to perform accurate analyses that are closer to reality.

The distinct visible landscape area approach provides the possibility of detecting the visual sensitivity of the mountain in relation to the areas from which buildings emerge in the horizontal viewing scene. The empirical findings support the figure-ground principle, as demonstrated in the ways in which the foreground, where buildings are located, and the background, where the mountain is located, relate to each other in the visual field. This research assists in locating buildings appropriately in places where volume and height constitute visual concerns. Furthermore, the specified view cone can be utilised as an indicator for future landscape quality analysis. In general, visual assessment can aid in the conservation of the aesthetic quality of cultural landscapes against invasive built environments. As a result, this study emphasised that, in Chiang Mai, it may not be necessary to locate only low-rise buildings; instead, it may be useful to consider horizontal visual zones as an effective method. Furthermore, the region we analysed was assigned based on the observers' visual limitations, so it only included the areas adjacent to the corridor under study. Because the mountain landscape has visual qualities that allow for a greater distance and a wider vista view, the studied regions were only a few kilometres long. An extension to certain locations that provide images of the city, such as other roads, important temples, and open spaces, could be useful to cover the whole viewing area. Additionally, the ways in which Chiang Mai establishes holistic connections between the mountain and the historic city, with the river as the main axis, should be investigated. Our analysis mainly focused on the impact of buildings; however, including vegetation and temporary structures would result in a more accurate evaluation.

The identification can be useful for city planning and conservation in Chiang Mai, as well as other cities with significant natural and cultural heritage landscapes. The results identify the areas and what to conserve in which locations, which can result in a future baseline for the built environment. A decrease in the visibility of significant areas means a decrease in connectivity between them, which results in a decrease in cultural landscape value. Cities must find a balance between conservation and development, especially in the historic neighbourhoods of rapidly growing cities; this balance is especially important in mountainous regions. The built environment should be carefully planned with respect to its broader setting.

Acknowledgements

Authors would like to express deeply gratitude to the Department of Civil Engineering and Architecture for Doctoral student position during the research conducted. This study was supported by JSPS KAKENHI Grant Numbers JP20KK0101, JP20F40066, and conducted as a research of the ICT Machizukuri Design project of SDGs research institute at Saga University.

Authors' contributions

J.S. designed the study, conducted the analysis, interpreted the conclusion, and contributed to the mapping of Chiang Mai city. N.M. and N.S. conceived of the study, discussed the analysis, and participated in revising the manuscript. All persons designated as authors qualified for authorship, they sufficiently in the work to take public responsibility for portions of the content. J.S. as corresponding author takes responsibility for the integrity of the work from inception to published article. All author(s) read and approved the final manuscript.

Funding

The paper is supported by JSPS KAKENHI Grant Numbers JP20KK0101, JP20F40066.

Availability of data and materials

The datasets generated during and/or analysed during the current study are not publicly available due to [CONTAINING INFORMATION THAT COULD COMPROMISE RESEARCH PARTICIPANT PRIVACY] but are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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Received: 3 January 2022 Accepted: 30 August 2022
Published online: 30 September 2022

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