How visible are the valley slopes in the city? A viewshed analysis in the urban agglomeration of Liège.

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Conflicts of Interest

The authors declare no conflicts of interest.

ABSTRACT

Valley slope is a cultural and ecological resource of many cities that has gained attention in recent decades. Even if valley slopes are the background of numerous cities, they are scarcely considered by 'Viewshed Analysis'. In urban areas, the focus is on the visibility of individual biotic or abiotic elements, such as trees or buildings, assessing the impact of isolated components rather than understanding the place's topography. This contribution experiments with valley slope viewshed analysis through a case study of Liège's urban agglomeration. We propose a methodology articulated through the combination of GIS mapping, statistical analysis and photographic survey to address gaps related to the identification of valley slopes' visibility in an urban agglomeration and to investigate the elements of urban form that influence its visibility. The research highlights different degrees of valley slope visibility and different ways of urban form influencing it.

KEYWORDS

Valley slope; Viewshed analysis; Urban Morphology; GIS; Liege.

MAIN TEXT

Introduction

Reconsidering Valley Slope

Observing the geomorphological matrix of a site is the starting point of the relationship we can establish with the natural environment. Among the various observable landforms, this contribution reflects on the visual analysis of valley slopes, defined as sloping topographic surfaces between a line of high and low points converging to the elongated shape of a river in a valley. Based on the case study of Liege conurbation in Belgium, the research analyses the visual links between a medium-sized city and its hilly surroundings. Many cities have grown near rivers, which, according to the climatic and geological context, have developed more or less pronounced valley slopes.

Consideration of valley slopes in an urban context is often linked to acquiring information on the spatial distribution of mass movements (Zwoliniski et al. 2021) or studying urbanization's effects on the hydrology and quality of watercourses (Sung and Li 2010). However, valley slopes have recently been promoted as a cultural and ecological resource, constituting a new balance between people and the environment and capable of expression through the themes of living (Csima 2010), biodiversity (Franch 2018), mobility (Greenberg, Natapov and Fisher-Gewirtzman 2020) or recreation.

Determining which areas of the urban form benefit from greater visibility of a valley slope is important in order to consider areas of transformation, with potential privatization of the view influencing house prices, and to protect valley slopes as areas that provide physical and mental benefits linked to the presence of vegetation (Joye and Van den Berg 2018).

A literature review on 'Viewshed analysis' in relation to landforms reveals a fragmented picture and inadequate attention to points that this contribution intends to address, by experimenting with valley slope viewshed analysis through the case study of Liège's urban agglomeration as follows:

- Identifying — and consequently representing — valley slope visibility in correspondence with an urban agglomeration;
- Combining information from digital models as a critical filter to integrate quantitative dimensions and experience on the ground to investigate which urban forms influence valley slope visibility.

Landforms in 'Viewshed Analysis'

To understand whether and how landforms are the subject of visibility studies, we conducted a preliminary analysis of the scientific literature using the keyword 'Viewshed analysis' on the Scopus platform. The result is a set of 574 abstracts providing insight into the topics that relate to the study of visibility, and the cultural approaches and operational methods that consider landforms. Overall, 'Viewshed analysis' interlinks with a heterogeneous and fragmented framework of applications (Figure S1).

More than a third of the abstracts (37 percent) refer to 'Landscape and Urban Planning' and just under a quarter (22 percent) to 'Archaeology and Heritage Studies'. However, other fields, such as 'Ecology and Biology' (4 percent), 'Security' (8 percent) and 'New technologies' (2 percent) are also present.

In the sub-discipline of 'viewshed ecology' (Lecigne, Eitel and Rachlow 2020), a new field of study referring to visual analysis is emerging as a tool for understanding behaviours or factors influencing animal welfare (Ucero et al. 2023) or the reasons for the density and spread of plant species (Kizuka et al. 2014). Landforms are also excluded from visual analyses that address the topic of security, mainly concerned with the positioning of objects in the landscape to control the spread of fire (Drosos et al. 2023), the operation of surveillance systems (Zhou et al. 2024), or the conduct of military operations (Henrico I., Henrico S. and Coetzee 2020).

In addition to a progressive diversification of the field of applications, there is also an increasing interest (27 percent) aimed at improving data acquisition and management of digital models because of a need to improve data sharing (Guo, Huang and Xie 2015), but also concerning a particular and heterogeneous set of possible study environments, such as urban (Mayalu et al. 2020), submarine (Wawrzyniak, Wlodarczyk-Sielicka and Stateczny 2017), archaeological (Brughmans, van Garderen and Gillings 2018), forest (Zong et al. 2021) or indoors (Bot, Nourian and Verbree 2019).

In Landscape and Urban Planning, there is a prevalent interpretation of visual analysis based on technical-scientific dimensions. The action of seeing is used to assess, in the natural environment, which points are most visible as a function for planning routes to stimulate recreational use of places (Lee et al. 2019) or, in the urban environment, the price or value of housing (Dai, Felsenstein and Grinberger 2023) or offices (Turan et al. 2021). The same technical-scientific dimension leads back to studies concerning the visual or environmental impact of objects in the landscape (Piskorski, Pyka and Jasińska 2022), particularly regarding renewable energy (Dong and Lang 2022).

Topography is mentioned when the analysis is applied to contexts generically considered 'natural', such as islands (Levin, Singer and Lai 2013), forests (Lehto et al. 2024) or mountains (Egarter et al. 2017). In urban environments, a focus is on the value of 'absolute' or 'conditional' visibility of individual biotic elements or areas, such as trees (Cimburova, Blumentrath and Barton 2023); or abiotic elements, 'relative' to the sequence of points along mobility infrastructure (Millar et al. 2021), or on the intervisibility of particular areas and points concerning the urban context, such as financial districts (Talamini et al. 2023) or cell towers (Acharya, Basu and Hanink 2022).

An opposite and complementary trend is highlighted in 'Archaeology and Heritage Studies.' Susmann (2020) emphasizes how visual analysis corresponds to understanding the interactions between topography and human perception in the study of the past. Differing from geometric and quantitative studies, and from a reduction of landscape to an exclusively scenic-aesthetic dimension, according to Lake and Ortega (2016), this brings the subject of visibility back to a humanistic dimension based on perception. In the search for historical truths rather than design projections, what is interesting is how the topography of a site is predominantly placed at the centre of visibility analysis; as a filter for understanding the evolution of an urban form

(D'Altilia and Favia 2019), the reasons for the position of an abiotic (Edwards 2020) or biotic (Karimi 2024) element in relation to the natural environment, sociopolitical interactions through the spatial configuration of a site (Moonkham, Srinurak and Duff 2023) or the reasons for the location of an agglomeration due to the influence that topography exerts over other sites (Calderón and Carretero Poblete 2017).

Although the digital terrain model (DTM) is predominantly the most widely used basis for analysis, Gillings (2017) and Sang, Miller and Ode (2008) point out that reduction to a planimetric evaluation cannot be sufficient. Germino et al. (2001) and Llobera (2003) have already discussed that a DTM does not capture the relief characteristics regarding diversity and land cover. Dong, Lang and Parent (2024) highlight how information from a DTM does not correctly assess the visual impact of an object, suggesting that information from the DTM should be compared with the digital surface model (DSM). Even in DSM, certain ways of handling the data, e.g., the standard height assigned to vegetation, are elements of discussion (Palmer 2016). DSM can distort the results of visibility analysis as it cannot show visibility under tree crowns (Parent and Lei-Parent 2023). Visibility analysis on 3d models gives more realistic results than DSM, even though it is much more complicated (Orlof et al. 2024; Klouček et al. 2015).

From this review, we highlight the experimentation of new protocols for a better acquisition of data referring to abiotic and biotic components in the absence of DSM (Mikita et al. 2023), but also a large field of reflections suggesting the integration of the digital model with other tools such as photographic survey (Santosa et al. 2023; Tomko, Trautwein and Purves 2009). Classical planimetric analyses obtained through DTM or DSM are thus often compared with images, explicitly taken by the inhabitants (Sherren et al. 2011), collected through the use of social media (Sottini et al. 2019) or through the researcher's own field experience (Brabyn and Mark 2011). Beyond integrating the digital model with photography, some contributions discuss the analysis in light of interviews with inhabitants (Garcia-Martin et al. 2007).

Contributing Trajectories and Research Questions

The analysis of the different themes and the variety of methods shows how visual analysis constitutes a primary condition for the knowledge, recognition, evaluation and appreciation of places and their characteristics (Romani 2008), as well as a field of application open to further investigation. Exploring the dimension of the landscape, mainly with reference to the analysis of an urban environment, reveals a lack of attention paid to understanding the visibility of topography.

In the framework of the city as an ecosystem (Newman 1999) and the need to integrate 21st-century cities into natural systems rather than inserting nature into the city (Balmori 2010), this contribution discusses the possibility of reintroducing valley slope as a subject of urban metabolism, beginning to understand how much and how this geomorphological matrix is seen in the city. Beyond sectoral considerations related to the analysis of landslide movements and floods, we, therefore, intend to return our attention to the valley slope through the following research questions:

- How visible are valley slopes in an urban agglomeration?
- Which methodologies could be used to assess valley slope visibility?
- What elements of the urban form influence their visibility?

The contribution is developed by framing the discussion in the context of the Liège agglomeration. Section 2 describes the methods used to identify valley slope visibility and visibility types. These are useful for integrating the analyses carried out through the digital models with those performed on the ground. Section 3 highlights the main results obtained and the limits of the methodology tested. Section 4 offers a synthesis of the potential that emerged, concerning the comparison with current and previous urban planning instruments and the different visibility conditions observed, concluding by highlighting further possible research perspectives.

Materials and methods

Context of research

The investigation focuses on Liège's urban agglomeration.

The Liège conurbation (600.000 inhabitants) is an expression of an urban form belonging to a geomorphological context of a low mountain range (between 50 m and 300 m drop). Prosperous in the Middle Ages, the city experienced significant growth during the 19th and 20th centuries, linked to the Industrial Revolution and the proliferation of metalurgy plants and coal mines. Its main urban building fabric characteristics are attributable to the European type (maximum height of buildings around six stories), which is also observable in non-European contexts.

The city is situated in the Meuse Valley on the border between the discrete topography of Middle Belgium in the north and the more elevated and deeply incised landscapes of Upper Belgium in the south (Demoulin 2018). Three rivers separate three agro-geographical regions to which three promontories correspond: Hesbaye in the north, Condroz Ardennais in the south, and Herve in the east. Founded in the ninth century, the city grew strongly with the development of the steel industry and coal mining during the nineteenth and twentieth centuries. The valley slopes, representing a third of the agglomeration surface and with about 90 m drop, were an obstacle that shaped urbanisation. Their surface area is mainly covered by pastures (51 percent) and forest (23 percent).

An earlier phase of research, informing this contribution, identified valley slope following an interscalar logic to structure it into lower, intermediate and higher taxonomic units (Dallatorre, Pepe and Schmitz 2024); in particular, by identifying valley slope starting from the minimum geographic units that compose it, then grouping them according to their interaction with higher dimensional units (agro-geographical regions), and at an intermediate scale, concerning the presence of physiognomically homogeneous sectors within the same set (geofacies), distinguished between extroverts ('Escarpments', 'Terraces') and introverts ('Branched valleys', 'Linear valleys', 'Amphitheatres').

The research method follows two consecutive steps and combines GIS (QGIS 3.32), statistical analysis (RStudio) and a photographic survey (Figure 1). We used the plug-in 1.9 developed by Zoran Čučković for QGIS 3.38 for visibility analysis, while the lm and aov functions for linear regression and anova. First, we suggested a viewshed analysis based on DTM and DSM to identify the valley slope's visibility according to the geofacies and the areas of the municipalities. We used the Shapiro-Wilk Test for the statistical distribution of DTM and DSM. Then, we conducted a photographic survey, focusing on a sample overlaying different visibility degrees resulting from DTM and DSM.

Materials and methods to identify visibility

Viewpoint selection

Using the extent of the area joining the four municipalities with the highest density, we created a grid of quadrants with 400 m sides; we used the latest aerial photography to place a viewpoint in each quadrant (Figure S2), based on the following criteria. We exclude lands occupied by private buildings or private annexes and put the point in an open space with the probability of being frequented. In the case of co-presence in the same quadrant of privileged places of rest — e.g., squares or other collective open spaces — and places of movement — e.g., highway — we selected open spaces. In addition, based on aerial photography, we placed the point where there is a lower density of elements, which can potentially influence the extent of the view on the DSM.

Viewshed creation

For each point (906), we created a viewpoint with a 20km Radius of analysis and a 1.75 m observer height. We interrogated DTM and DSM from Lidar acquisitions in 2021 and 2022 — both with a resolution of 0.5 m — through the 'Viewshed function', according to two different procedures:

- Overlay of the calculation results in a single raster (Analysis type: binary viewshed with cumulative function);
- Calculation of individual viewsheds corresponding to each viewpoint (Analysis type: binary viewshed).

Analysis of a single raster resulting from the viewshed obtained with the cumulative function

Using the valley slope set as masks, we cropped the rasters obtained by overlay calculations in the DTM and DSM. We vectorized the intersection and intersected it with the geofacies information layer. A vector map indicates the number of points from which each pixel is visible. We decomposed each surface of the geofacies into surfaces associated with different degrees of visibility. The largest surface determines the degree of visibility of the geofacies.

The result from the Shapiro-Wilk Test highlights that DTM and DSM are not normally distributed. Therefore, we used a square root transformation before proceeding with an ANOVA between geofacies. Finally, we applied the Tukey HSD function to visualize and compare the mean of the category of geofacies at a 5 percent threshold. These data identify the predominantly visible geofacies and the visibility variance in valley slope within each geofacies category.

Analysis of rasters resulting from the viewshed obtained for each viewpoint

We cropped each raster generated from each viewpoint in DTM and DSM using the valley slope set as a mask. Then, we calculated the visible area for each cropped raster using the function "Raster Area Calculation" in QGIS. We thus associated each viewpoint/quadrant with a number indicating the visible area of the valley slope expressed in hectares (ha). We used these data to identify visibility classes (A.Low, B.Medium, C.High) and jointly their relative distribution and percentages, through the thresholds observed, for each of the two models, in the related distribution histogram. We used the same data to measure the correspondence of the DTM and the DSM through a simple linear regression and subjected them to a process of overlay by subtraction (DTM-DSM). We preceded this operation by normalizing the data using 'Mean' and 'Standard deviation' to ensure a better comparison of variables. We analyzed the distribution of the variables obtained through overlay by subtraction using a histogram to identify three different types of visibility corresponding to different levels of influence (A.DTM < DSM; B.DTM=DSM; C.DTM > DSM).

The cartographies obtained are finally subject to a data generalization procedure. We used the latest aerial photography to approximate the urban agglomeration's form of individual or groupings of quadrants, converted into visibility regions to better relate/align the result to topography and land use.

Materials and methods to qualify visibility

We used the mapping of visibility types to establish a link between the quantitative analyses conducted in the laboratory and the qualitative analyses conducted in the field in December 2024.

Based on the results obtained in the first phase, we selected a sample using the influence of the DSM on the DTM as a criterion. We selected 60 public spaces — grouped in 15 quadrants of 800x800m side (about 15 percent of the total) — to investigate on the ground the implications related to the type of visibility C (DTM > DSM), to analyze which elements of the urban form influence the valley slope's visibility.

We explored each grouping of four quadrants in the field to construct for each of the selected viewsheds a sheet card that contains:

- one scheme indicating the position of the viewshed with reference to the four municipalities;
- two maps relative to the valley slope's surfaces visible in the DTM and DSM;
- one photograph corresponding with the selected viewpoint, taken with a 55 mm focal length, 32° angle of view, and identifying as the vanishing point the length of the widest view allowed;
- a summary of the data related to each viewshed, expressed in information:
  - quantitative, referring to the first phase, relative to visibility in the DTM and DSM (ha/classes), type of visibility in DTM-DSM, municipality, position according to topography (valley, valley slope, plateau) ;
  - qualitative, related to the second phase, relative to the type of environment and urban fabric explored on the ground, verified based on the Map of types of Walloon residential urban fabric, and to the reading of the photograph, i.e., to the distinction of the elements of the urban form visible in the foreground, in the intermediate plane and the background.

Results

Results obtained in the laboratory

Calculations using the DTM show that the highest visible valley slope reaches 455 viewpoints (Figure 2). Both the digital terrain model and the surface model indicate the existence of surfaces that are not visible from any selected point. On the other hand, according to the DSM, the maximum visibility of a valley slope is 106 points (Figure 3), showing an influence of elements above the surface. Both ANOVA tests show that the degree of visibility is highly influenced by the different slope structures (Figure S3). The visualization of the results, through the DTM (Figure 2), shows higher visibility of escarpments, followed by terraces, amphitheaters and linear and branched valleys. Using the DSM (Figure 3), higher visibility concerns branched valleys, followed by escarpments and, finally, amphitheatres, terraces, and linear valleys.

The visibility distribution varies depending on the inclusion or exclusion of features above the surface. Moreover, both models show the presence of visibility that deviates from the prevailing averages. The simple linear regression (Figure S3, S4) also shows a highly significant relationship between the variables obtained (*p-value* < 2.2e-16), highlighting, however, that the DTM visibilities can only explain those of the DSM by around 12 percent.

The second set of results focuses on analyzing the visibility of individual viewpoints derived from DTM, DSM and their overlay by subtraction.

The distribution of classes identified through histogram analysis for the DTM (Figure S5) shows a prevalent higher percentage of medium visibility (71.8 percent) compared to the percentages of low (16.1 percent) and high (12 percent) visibility. On the other hand, the DSM (Figure S6) shows a higher percentage of low visibility (65.4 percent), followed by medium (32.5 percent) and high (2 percent). The overlay (Figure 4) shows a prevailing correspondence between the values of the two models (60.9 percent), underlining that the elements above the surface influence visibility for about a quarter of the sample (24.6 percent) and that half of the previous percentage shows the opposite (12 percent). While normalizing the data, only a tiny percentage of the overall sampling (2.5 percent) is not helpful in the laboratory for understanding the relationship between the two models.

Redrawing the shape of the urban agglomeration allows a better analysis of the distribution of the previous percentages with respect to topography and land use (Figure 5).

The DTM (Figure 5A) indicates medium visibility concentrated mainly in the valley area, low visibility localized north of the Hesbignon plateau or in the narrow tributary valleys, and high visibility that predominantly gravitates around the intersection of the rivers, i.e., at the meeting point of the three promontories of the three agro-geographical regions.

The DSM (Figure 5B) shows a concentration of low visibility along the north-south cardinal axis that, by including the valley area around the city centre, homogenizes areas previously occupied by low, medium and high visibility. High visibility is still concentrated by points rather than areas around the three plateaus. Finally, despite predominantly industrial use (Figure 5D), medium visibility is concentrated with greater significance along the valley area and, with greater density, to the northeast and southwest, corresponding with the greater extent of the bed of the Meuse.

In the difference between the two models (Figure 5C), Type B (DTM=DSM) is mainly distributed in the valley area, at the southern ends of the Condroz Ardennais and north of the Hesbignon plateau. Type A is concentrated in points along the axis of the Meuse, corresponding with the soils resulting from the greatest widths of the river bed. Values not classified by standardization (NC) are distributed on the Hesbignon and Condroz Ardennais plateaus or the slope between the valley and the Herve promontory, in both cases, corresponding with areas intended for recreation, agriculture or forestry; an exception is an area in the central part of the Hesbignon plateau, which corresponds to a motorway infrastructure axis.

Type C (DTM > DSM) shows the influence of urbanization in the valley around the town center, beyond which, on the Hesbignon plateau, two further circular areas gravitate. Type C is also distributed on the Condroz Ardennais in a predominantly linear manner, including, in addition to the residential fabric, areas designated for forestry or indicated as 'natural reserve' (Figure 5D).

Results from the field

Through an analysis of the data and schedules of the selected viewsheds (Figure S7) and a summary (Figure 6, Figure S8), we present the results of the in-situ exploration with an account of which elements influence the valley slope's visibility and the methodological limitations that emerged from the comparison between the types of visibility identified in the laboratory and the observed visibilities.

The conditions on the ground investigated through the analysis of the Type C samples allow us to identify a heterogeneous set of elements influencing visibility. More recent sanitary structures built on the plateau (Photo 240) and landfills from railway infrastructure in a residential area (Photo 790) affect the possibility of observing the valley slope.

Different types of residential fabric — semi-continuous extensions (Photo 566), in ribbon (Photo 434), older continuous (Photo 135), extension continuous (Photo 790) — similarly influence the poor visual interaction found on the terrain. The heights of the residential fabric induce poor visibility from the public space, even in less artificial environments, such as urban parks in a valley setting, not allowing us to cross the intermediate plane (Photo 507). There are exceptions due to viewpoints referring to the same type of urban fabric but positioned differently: concerning road alignments, parallel or orthogonal to valley slope (Photo 565, 566) and the geomorphological structure of the valley, on the plateau or in correspondence with valley slope (Photo 434, 18).

In addition to abiotic components of the urban form, biotic ones, particularly trees, also influence visibility. Evergreen trees, for example, are elements that, even in anthropized environments such as playgrounds within residential fabric, do not allow the full extension of the view beyond the intermediate plane (Photo 17).

However, the vegetation information in the DSM is insufficient to provide the actual depth of the field of view and, consequently, an exhaustive differentiation of the variety of ways valley slope can be observed.

Near or in environments with a predominance of trees and shrubs — forests (Photo 324), urban parks (Photo 499), nature reserves (Photo 655), and cemeteries (Photo 901) — the upper profile of the valley slope is still distinguishable due to the vegetation's senescence mechanism in winter.

Predominantly, the methodology verifies that Type C corresponds to low visibility conditions. However, trees (Photo 537) or high-tension pylons (Photo 280), on the ground, whether in the foreground or the background, do not preclude an effective visual relationship with the valley slope. Another exception is related to the normalization of the data: medium-high classes in DTM and DSM are standardized to Type C, but in the field, the visibility corresponds to good visibility in both digital models (Photo 791).

Type B (DTM=DSM) does not allow us to predict the visibility observed in the field.

On the one hand, Type B includes average values actually found in the terrain (Photo 565), on the other hand, low-medium values sometimes correspond to a predominant presence of valley slope in the background (Photo 654, 692), again in contexts with a significant presence of shrubs and trees, demonstrating an actual discrepancy between the calculation of these elements in the digital model and their actual influence on the observation in the field.

Even if the proposed method focused mainly on Type C and should be tested further to verify Types A (DTM < DSM) and NC, at a preliminary level, there is a correspondence between the high visibility values calculated in the two models and the visibility observed in residential areas for Type A (Photo 18). The non-classification corresponds to areas of exceptionally high visibility in edge conditions between the plateau and valley slope, in areas recognized by the population as significant places for recreation (Photo 500) and with no evidence of appropriation by inhabitants (Photo 6).

Discussion and conclusion

Through this contribution, we tested a methodology, combining the questioning of digital models and field experience, to investigate valley slope as a particular landform poorly considered in viewshed analyses in urban settings. Yet, these landforms are the horizon and the backdrop of many cities.

From a methodological point of view, the results highlight some limitations. In particular, certain elements of the urban form — trees or high-tension pylons — present different degrees of influence on the visual field's depth in the digital environment and the ground. The superimposition by subtraction preceded by the normalization of the data makes it possible to effectively determine which environments in the urban form influence the valley slope's visibility and show gaps related to the excessive uniformity of high-medium classes in DTM and DSM.

Beyond the highlighted limitations, the identification of different degrees of valley slope visibility emerges and an understanding of the urban form's elements influencing it according to land use, different environments, and the immersive conditions explored. Returning to the question of reconsidering landform as a natural resource nurturing urban metabolism, in this sense, the valley slope's visibility allows us to discuss different challenges and perspectives.

Some slope categories, including terraces and amphitheatres, accommodate numerous constructions, which reduce the view. On the other hand, escarpments or branched valleys preserve slopes with significant degrees of visibility due to the reduced influence of the built residential fabric. In addition to landslides and management of water run-off, possible urbanization of these areas will have to consider the disappearance of agricultural land, characterizing the culture of agro-geographical regions, resulting from possible privatization of the valley slope's view, as in the so-called 'garden-city' of Cointe (Photo 434; Ville de Liège 2023b, 48).

Interrogating the DSM, a medium visibility was found mainly in the downstream area, where the river beds are wide and there is a significant presence of disused industrial buildings. In reconsidering the relationship with the river and, in particular, in the hypothesis of building along the Meuse 'more than 10,000 dwellings' (Ville de Liège 2023a, 11), we highlight the importance of enhancing not only the relationship with what is in front of it, the river, but also that of reconsidering the continuity between the river and what is behind it. This relationship, especially around the middle of the twentieth century, was scarcely considered, for instance, in the 'Regulation on building heights', adopted by the city in 1963 (Ville de Liège 2023b, 86). There were consequent iimpacts on a poor visual and ecological continuity between valley and plateau, also found in frequented areas like urban parks (Photo 507).

There are different ways of observing forest environments on the valley slope or the edge between the valley slope and the plateau. When observed from within, these environments tend to be visually isolated, as well as from sound, from the more built-up urban agglomeration; when observed from the plateau (Photo 500) or in valley settings (Photo 537), they can instead be considered as an integral part of the urban form. Reconsidering valley slope as an active subject within the urban metabolism, therefore, suggests further directions of study concerning the social and ecological benefits that visual, as well as physical, proximity to an existing urban forest (Konijnendijk 2022; Simson 2017), might offer to populations.

A final element of discussion concerns the potential of reconsidering valley slopes as a valuable subject to imagine, between plateau and river, transversal urban areas with a high landscape value (Ville de Liège 2023a). This contribution has highlighted the importance of reconsidering the influence of possible urbanization along the river but also the importance of reconsidering the open marginal spaces between the plateau and valley slope, which, at the moment, do not show signs of protection, but instead present a high degree of visibility of the continuity of the underlying geomorphological structure (Photo 6).

Further methodological experimentation could integrate the spatiality of urban form among the criteria for selecting viewpoints with analyses concentrated on areas such as neighborhoods of the same agglomeration, individual geofacies, or interface zones between valley slope and plateau or valley. Visibility assessment could also be improved by including a dynamic condition of movement in space and head tilting among the variables to be considered. In addition to different degrees of visibility, the research highlights different ways of urban form influence and visual interrelation with valley slopes that should be considered in urban planning as cultural, ecological or recreational resources for populations. Towards this perspective, the analysis of visibility also suggests how results of a more objective nature involve a reflexive dimension aimed at understanding 'landscapes', but also the 'meaning' they could be able to express (Vanderheyden et al. 2014).

In conclusion, this paper contributes in several ways. It presents the possibility of refining and testing the methodology in other contexts or scales. It also relates to the possibility of integrating the methodology to understanding the evolution of the urban form, that following different planning trajectories, may have influenced the visibility and meanings attributed to valley slope. It can also be integrated with further methods aimed at combining the visible dimension with subjective representations, or perceptions, coming from the potentially involved local population. In this latter way, the methodology provides potential to reflect on the meanings of ‘Seeing valley slopes in the city’ through an understanding of that ‘invisible’ dimension of the landscape, which digital models and photographs may not be able to comprehend.

REFERENCES

Acharya, A., S. Basu, and D.M. Hanink. 2022. Spatial Hedonic Regression Analysis of the Impact of Cell Towers on Las Vegas Real Estate Market. *The Professional Geographer*, 74(4): 715–726. DOI: 10.1080/00330124.2022.2048866.

Balmori, D. 2010. *A Landscape Manifesto*. New Haven: Yale University Press.

Bot, F.J., P. Nourian, and E. Verbree. 2019. A graph-matching approach to indoor localization using a mobile device and a reference bim. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 42(2): 761–767. DOI: 10.5194/isprs-archives-XLII-2-W13-761-2019.

Brabyn, L., and D.M. Mark. 2011. Using viewsheds, GIS, and a landscape classification to tag landscape photographs. *Applied Geography* 31(3): 1115–1122. DOI: 10.1016/j.apgeog.2011.03.003.

Brughmans, T., M. van Garderen, and M. Gillings. 2018. Introducing visual neighbourhood configurations for total viewsheds. *Journal of Archaeological Science* 96: 14–25. DOI: 10.1016/j.jas.2018.05.006.

Calderón, D.F.M., and P.A. Carretero Poblete. 2017. Archaeological landscapes analysis of basin viewshed at the puruha site of collay. *Arqueologia Iberoamericana* 36: 43–47. DOI: 10.5281/zenodo.1478266.

Cimburova, Z., S. Blumentrath, and D.N. Barton. 2023. Making trees visible: A GIS method and tool for modeling visibility in the valuation of urban trees. *Urban Forestry and Urban Greening* 81:127839. DOI: 10.1016/j.ufug.2023.127839.

Csima, P. 2010. Urban Development and Anthropogenic Geomorphology. In: *Anthropogenic Geomorphology: A Guide to Man-Made Landforms*, eds Szabó, J., L. Dávid, and D. Lócz, 179–187. Dordrecht: Springer. DOI: 10.1007/978-90-481-3058-0_12.

d'Altilia, L., and P. Favia. 2019. The medieval site of Montecorvino (FG) and its territory. Spatial analysis in Open Source GIS environment. *Archeologia e Calcolatori* 30: 507–510. DOI: 10.19282/ac.30.2019.41.

Dai, X., D. Felsenstein, and A.Y. Grinberger. 2023. Viewshed effects and house prices: Identifying the visibility value of the natural landscape. *Landscape and Urban Planning* 238: 104818. DOI: 10.1016/j.landurbplan.2023.104818.

Dallatorre, G., L. Pepe, and S. Schmitz. 2024. Rediscovering Valley Hillslopes: Their Forms, Uses, and Considerations in Urban Planning Documents. *Land* 13(9): 1353. DOI: 10.3390/land13091353.

Demoulin, A. 2018. *Landscapes and Landforms of Belgium and Luxembourg*. Berlin/Heidelberg: Springer International Publishing AG.

Dong, L. and C. Lang. 2022. Do views of offshore wind energy detract? A hedonic price analysis of the Block Island wind farm in Rhode Island. *Energy Policy* 167: 113060. DOI: 10.1016/j.enpol.2022.113060.

Dong, L., C. Lang, and J. Parent. 2024. Focusing the view: Improved methods for assessing viewshed impacts of onshore wind turbines. *Journal of Environmental Economics and Management* 128: 103068. DOI: 10.1016/j.jeem.2024.103068.

Drosos, V.C., I. Kasapidis, V.T.h Stavridis, I. Sismanidis, and E.D. Farmakis. 2023. Early detection of forest fire and first intervention of fire-fighting units. In: *Ninth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2023)* eds Themistocleous, K., D.G. Hadjimitsis, S. Michaelides, and G. Papadavid. Ayia Napa, Cyprus, 3–5 April 2023. DOI: 10.1117/12.2681925.

Edwards, S. 2020. On the Lookout: Directional Visibility Cones and Defense in the Nebo Region, West-Central Jordan. *Open Archaeology* 6(1): 2–18. DOI: 10.1515/opar-2020-0002.

Egarter Vigl, L., D. Depellegrin, P. Pereira, R. de Groot, and U. Tappeiner. 2017. Mapping the ecosystem service delivery chain: Capacity, flow, and demand pertaining to aesthetic experiences in mountain landscapes. *Science of the Total Environment* 574: 422–436. DOI: 10.1016/j.scitotenv.2016.08.209.

Franch, M. 2018. Drawing on site: Girona's shores. *Journal of Landscape Architecture* 13(2): 56–73. DOI: 10.1080/18626033.2018.1553396.

Garcia-Martin M., N. Fagerholm, C. Bieling, D. Gounaridis, T. Kizos, A. Printsmann, M. Müller, J. Lieskovský, and T. Plieninger. 2017. Participatory mapping of landscape values in a Pan-European perspective. *Landscape Ecology* 32: 2133–2150. DOI: 10.1007/s10980-017-0531-x.

Germino, M.J., W.A. Reiners, B.J. Blasko, D. McLeod, and C.T. Bastian. 2001. Estimating visual properties of rocky mountain landscapes using GIS. *Landscape and Urban Planning* 53: 71–83. DOI: 10.1016/S0169-2046(00)00141-9.

Gillings, M. 2017. Mapping liminality: Critical frameworks for the GIS-based modelling of visibility. *Journal of Archaeological Science* 84: 121–128. DOI: 10.1016/j.jas.2017.05.004.

Greenberg, E., A. Natapov, and D. Fisher-Gewirtzman. 2020. A physical effort-based model for pedestrian movement in topographic urban environments. *Journal of Urban Design* 25(1): 86–107. DOI: 10.1080/13574809.2019.1632178.

Guo, M., Y. Huang, and Z. Xie. 2015. A balanced decomposition approach to real-time visualization of large vector maps in CyberGIS. *Frontiers of Computer Science* 9(3): 442–455. DOI: 10.1007/s11704-014-3498-7.

Henrico, I., S. Henrico, and S. Coetzee. 2020. A comparison between two DEM products to calculate a visibility analysis for military operations using FOSSGIS. *Geografia Fisica e Dinamica Quaternaria* 43(1): 157–165. DOI: 10.4461/GFDQ.2020.43.6.

Joye, Y. and van den Berg, A.E. 2018. Restorative Environments. In: *Environmental Psychology*, eds Steg , L. and J.I.M. Groot, 65-75. Willey. DOI:10.1002/9781119241072.ch7.

Karimi, E. 2024. The visual landscape of rock art in Qeydu Valley in Teymare in the Central Iranian Plateau. *Digital Applications in Archaeology and Cultural Heritage* 34: e00358. DOI: 10.1016/j.daach.2024.e00358.

Kizuka, T., M. Akasaka, T. Kadoya, and N. Takamura. 2014. Visibility from roads predict the distribution of invasive fishes in agricultural ponds. *PLoS ONE* 9(6): e99709. DOI: 10.1371/journal.pone.0099709.

Klouček, T., Lagner, O., Šímová, P. 2015. How does data accuracy influence the reliability of digital viewshed models? A case study with wind turbines. *Applied Geography*, 64: 46–54, DOI:10.1016/j.apgeog.2015.09.005.

Konijnendijk, C.C. 2022. Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: Introducing the 3–30–300 rule. *Journal of Forestry Research* 34: 821-830. DOI: 10.1007/s11676-022-01523-z.

Lake, M., and D. Ortega. 2016. Compute-intensive GIS visibility analysis of the settings of prehistoric stone circles. In: *Computational Approaches to Archaeological Spaces,* eds M. Lake, and D. Ortega, 213-241. London: Routledge. DOI: 10.4324/9781315431932-15.

Lecigne, B., J.U.H. Eitel, and J.L. Rachlow. 2020. viewshed3d: An r package for quantifying 3D visibility using terrestrial lidar data. *Methods in Ecology and Evolution* 11(6): 733–738. DOI: 10.1111/2041-210X.13385.

Lee, K.Y., J.I. Seo, K.N. Kim, Y. Lee, H. Kweon, and J. Kim. 2019. Application of viewshed and spatial aesthetic analyses to forest practices for Mountain scenery Improvement in the Republic of Korea. *Sustainability* 11(9): 2687. DOI: 10.3390/su11092687.

Lehto, C., M. Hedblom, A. Filyushkina, and T. Ranius. 2024. Seeing through their eyes: Revealing recreationists' landscape preferences through viewshed analysis and machine learning. *Landscape and Urban Planning* 248: 105097. DOI: 10.1016/j.landurbplan.2024.105097.

Levin, N., M.E. Singer, and P.C. Lai. 2013. Incorporating topography into landscape continuity analysis-Hong Kong Island as a case study. *Land* 2(4): 550–572. DOI: 10.3390/land2040550.

Llobera, M. 2003. Extending GIS-based visual analysis: the concept of visualscapes. *International Journal of Geographical Information Science* 17(1): 25–48. DOI: 10.1080/713811741.

Mayalu, A., K. Kochersberger, B. Jenkins, and F. Malassenet. 2020. Lidar data reduction for unmanned systems navigation in urban Canyon. *Remote Sensing* 12(11): 1724. DOI: 10.3390/rs12111724.

Mikita, T., L. Janoíková, J. Caha, and E. Avoiani. 2023. The Potential of UAV Data as Refinement of Outdated Inputs for Visibility Analyses. *Remote Sensing* 15(4): 1028. DOI: 10.3390/rs15041028.

Millar, G.C., O. Mitas, W. Boode, L. Hoeke, J. de Kruijf, A. Petrasova, and H. Mitasova. 2021. Space-time analytics of human physiology for urban planning. *Computers, Environment and Urban Systems* 85: 101554. DOI: 10.1016/j.compenvurbsys.2020.101554.

Moonkham, P., N. Srinurak, and A.I. Duff. 2023. The heterarchical life and spatial analyses of the historical Buddhist temples in the Chiang Saen Basin, Northern Thailand. *Journal of Anthropological Archaeology* 70: 101506. DOI: 10.1016/j.jaa.2023.101506.

Newman, P.W.G. 1999. Sustainability and cities: Extending the metabolism model. *Landscape and Urban Planning* 44(4): 219–226. DOI: 10.1016/S0169-2046(99)00009-2.

Orlof, J., Ozimek, P., Łabędź, P., Widłak, A., Ozimek, A. 2024. Generating viewsheds based on the Digital Surface Model (DSM) and point cloud. *PLoS ONE*, 19 (12), e0312146. DOI: 10.1371/journal.pone.0312146.

Palmer, J.F. 2016. Assigning a fixed height to land cover screen for use in visibility analysis. *Journal of Digital Landscape Architecture* 1: 125–132. DOI: 10.14627/537612015.

Parent J.R., Lei-Parent Q. 2023. Rapid viewshed analyses: A case study with visibilities limited by trees and buildings. *Applied Geography*, 154, 102942, DOI: 10.1016/j.apgeog.2023.102942.

Piskorski, R., K. Pyka, and A. Jasińska. 2022. LiDAR-based method for analysing landmark visibility to pedestrians in cities: case study in Kraków, Poland. *International Journal of Geographical Information* Science 36(3): 476–495. DOI: 10.1080/13658816.2021.2015600.

Romani, V. 2008. *Il paesaggio percorsi di studio*. Milano: Franco Angeli.

Sang, N., D. Miller, and Å. Ode. 2008. Landscape metrics and visual topology in the analysis of landscape preference. *Environment and Planning B: Planning and Design* 35(3): 504–520. DOI: 10.1068/b33049.

Santosa, H., A. Yudono, F.R. Sutikno, M.S. Adhitama, H. Tolle, and E. Zuliana. 2023. Visibility Evaluation of Historical Landmark Building Using Photographic Survey Coupled with Isovist and Viewshed Analysis. *International Review for Spatial Planning and Sustainable Development* 11(4): 71–92. DOI: 10.14246/irspsd.11.4_71.

Sherren, K., J. Fischer, J. Pink, J. Stott, J. Stein, and H.J. Yoon. 2011. Australian Graziers value sparse trees in their pastures: A viewshed analysis of Photo-elicitation. *Society and Natural Resources* 24(4): 412–422. DOI: 10.1080/08941920.2010.488686.

Simson, A. 2017. A landscape and urbanism perspective on urban forestry. In *Routledge handbook of urban forestry,* eds F. Ferrini, C.C. Konijnendijk and A. Fini, 194-204. London: Routledge.

Sottini, V.A., E. Barbierato, I. Bernetti, I. Capecchi, S. Fabbrizzi, and S. Menghini. 2019. Rural environment and landscape quality: An evaluation model integrating social media analysis and geostatistics techniques. *Aestimum* 74: 43–62. DOI: 10.13128/aestim-7379.

Sung, C.Y., and M. Li. 2010. The effect of urbanization on stream hydrology in hillslope watersheds in central Texas. *Hydrological Processes* 24: 3706–3717. DOI: 10.1002/hyp.7782.

Susmann, N.M. 2020. Regional Ways of Seeing: A Big-Data Approach for Measuring Ancient Visualscapes. *Advances in Archaeological Practice* 8(2): 174–191. DOI: 10.1017/aap.2020.6.

Talamini, G., T. Liu, R. El-Khoury, and D. Shao. 2023. Visibility and symbolism of corporate architecture: A multi-method approach for visual impact assessment. *Environment and Planning B: Urban Analytics and City Science* 50(9): 2407–2429. DOI: 10.1177/23998083231154587.

Tomko, M., F. Trautwein, and R.S. Purves. 2009. Identification of practically visible spatial objects in natural environments. In: *Advances in GIScience*, eds M. Sester, L. Bernard, and V. Paelke, 1–23. Berlin: Springer. DOI: 10.1007/978-3-642-00318-9_1.

Turan, I., A. Chegut, D. Fink, and C. Reinhart. 2021. Development of view potential metrics and the financial impact of views on office rents. *Landscape and Urban Planning* 215: 104193. DOI: 10.1016/j.landurbplan.2021.104193.

Ucero, A., J.C. Alonso, C. Palacín, I. Abril-Colón, and J.M. Álvarez-Martínez. 2023. Display site selection in a ground dwelling bird: the importance of viewshed. *Behavioral Ecology* 34(2): 223–235. DOI: 10.1093/beheco/arac112.

Vanderheyden, V., D. Van der Horst, A. Van Rompaey and S. Schmitz. 2014. A Study of Everyday Landscapes in Belgium. *Tijdschr Econ Soc Geogr*, 105: 591-603. DOI: 10.1111/tesg.12066

Ville de Liège. 2023a. *Manifeste. Synthèse des Grandes Ambitions Retenues par le Collège pour L'élaboration du «Projet de Territoire»*. Liège: Ville de Liège.

Ville de Liège. 2023b. *Schéma de Développement Communal - Histoire urbanistique*. Liège: Ville de Liège.

Wawrzyniak, N., M. Wlodarczyk-Sielicka, and A. Stateczny. 2017. MSIS sonar image segmentation method based on underwater viewshed analysis and high-density seabed model. In: *18th International Radar Symposium (IRS)* (ed Rohling H), Prague, Czech Republic, 28–30 June 2017, 1–9. Göttingen: Cuvillier Verlag. DOI: 10.23919/IRS.2017.8008210.

Zhou, X., W. Wang, Q. Huang, N. Feng, P. Han, and C. Wu. 2024. Sparse Multi-viewshed Analysis for Assisting Video Surveillance Network Location Optimization. In: *Proceedings of the 36th Chinese Control and Decision Conference*, Xi'an, China, 25–27 May 2024, 1687–1694. DOI: 10.1109/CCDC62350.2024.10587971.

Zong, X., T. Wang, A.K. Skidmore, and M. Heurich. 2021. The impact of voxel size, forest type, and understory cover on visibility estimation in forests using terrestrial laser scanning. *GIScience and Remote Sensing* 58(3): 323–339. DOI: 10.1080/15481603.2021.1873588.

Zwoliniski, Z., J. Jasiewicz, M. Mazurek, I. Hildebrandt-Radke, and M. Makohonienko. 2021. Geohazards and geomorphological setting in Poznan urban area, Poland. *Journal of Maps* 17(4): 202–214. DOI: 10.1080/17445647.2021.1950581.

FIGURE CAPTIONS

Figure 1 Methodological framework.

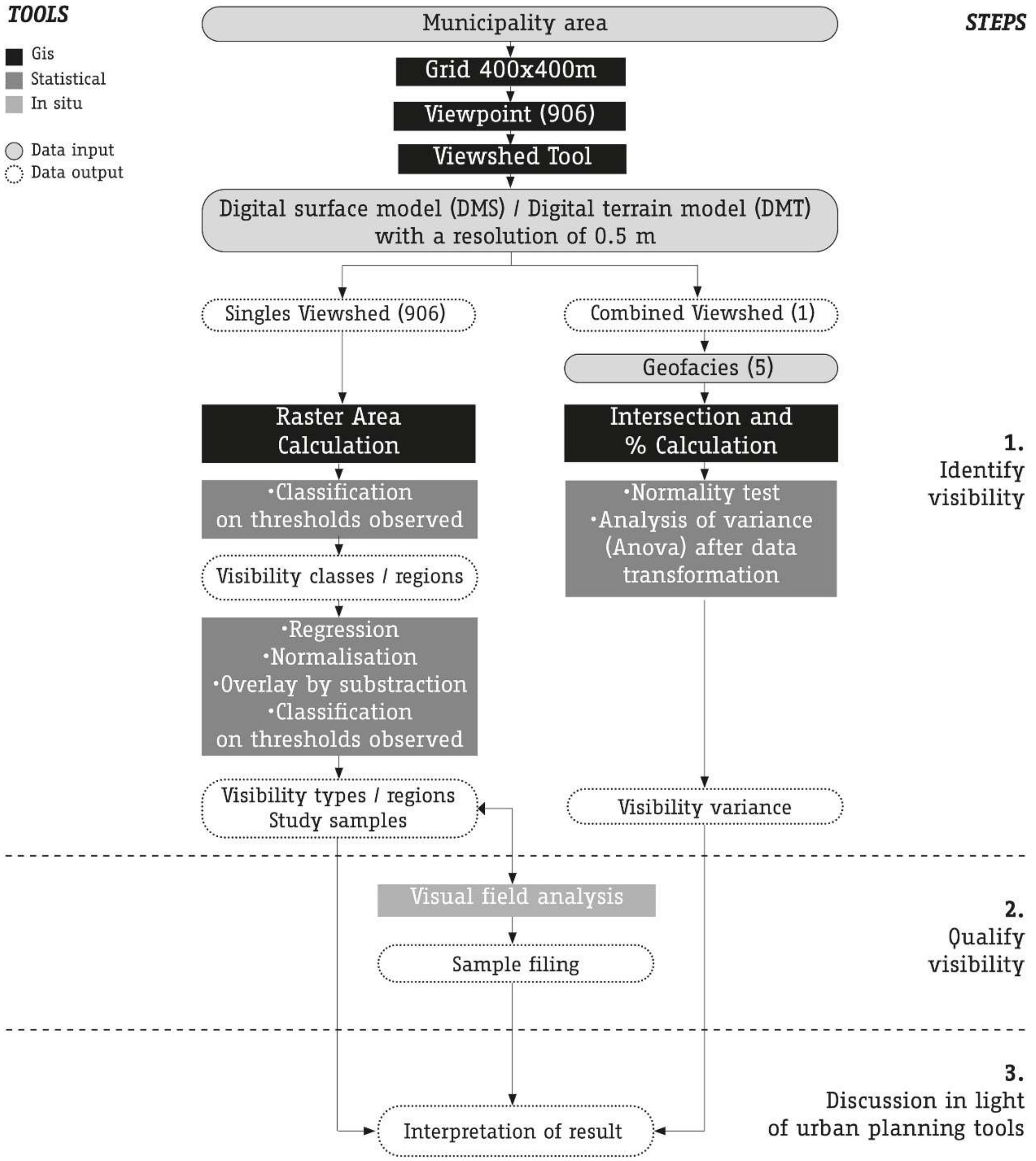
Figure 2 (A) Valley slope visibility distribution calculated from DTM intersected with geofacies. (B) Valley slope visibility resulting from DTM intersected with geofacies.

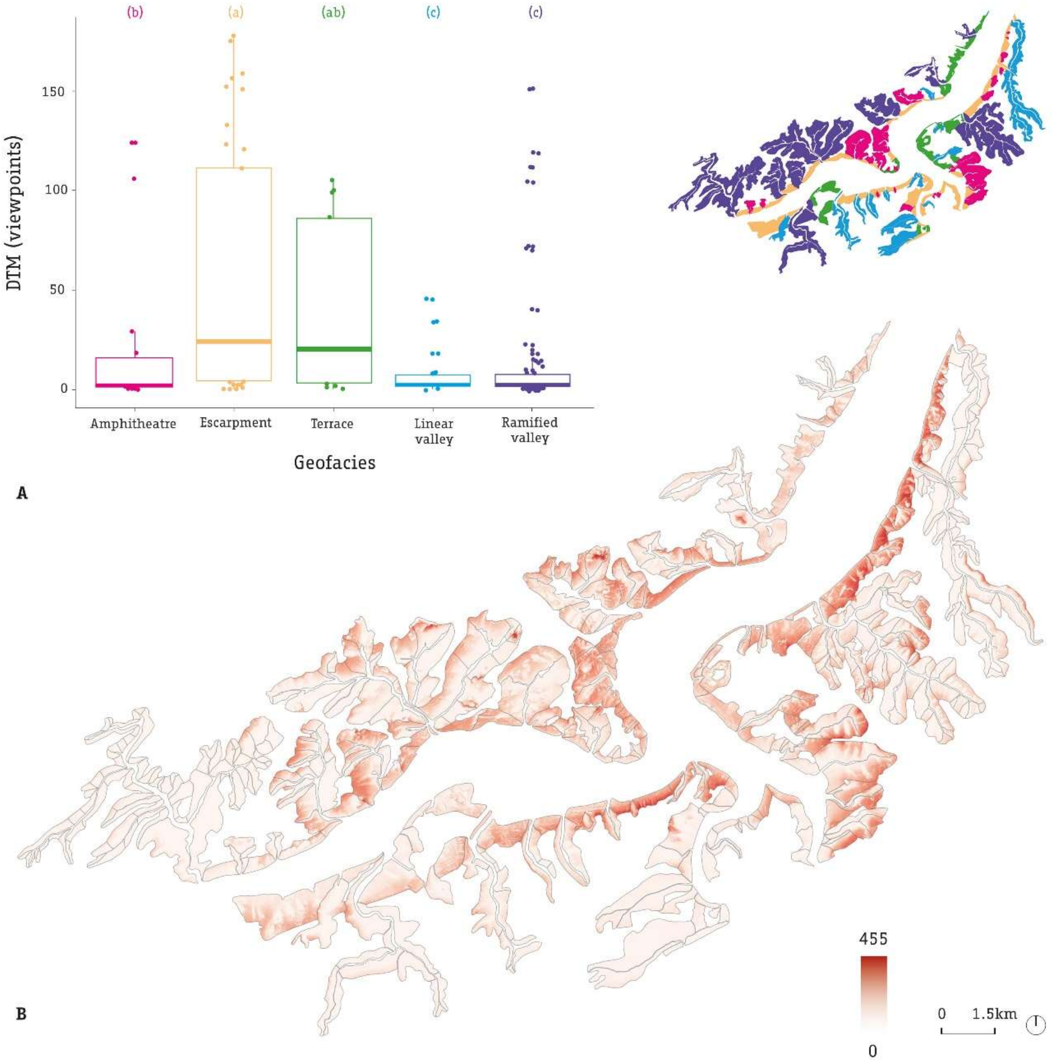
Figure 3 (A) Valley slope visibility distribution calculated from DSM intersected with geofacies. (B) Valley slope visibility resulting from DSM intersected with geofacies.

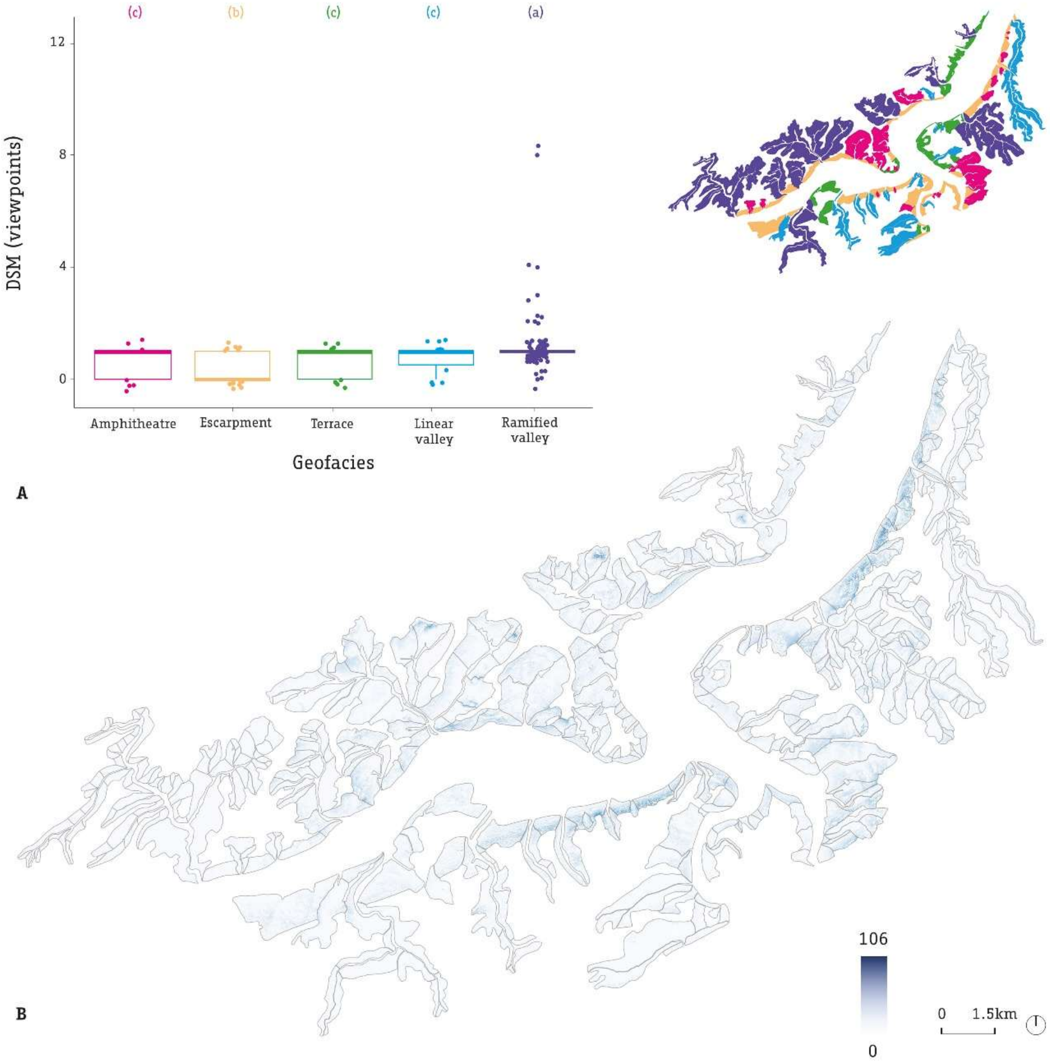
Figure 4 Visibility types obtained from overlay by subtraction between DTM and DSM: histogram for type identification, map of quadrants divided by identified types and relative percentages.

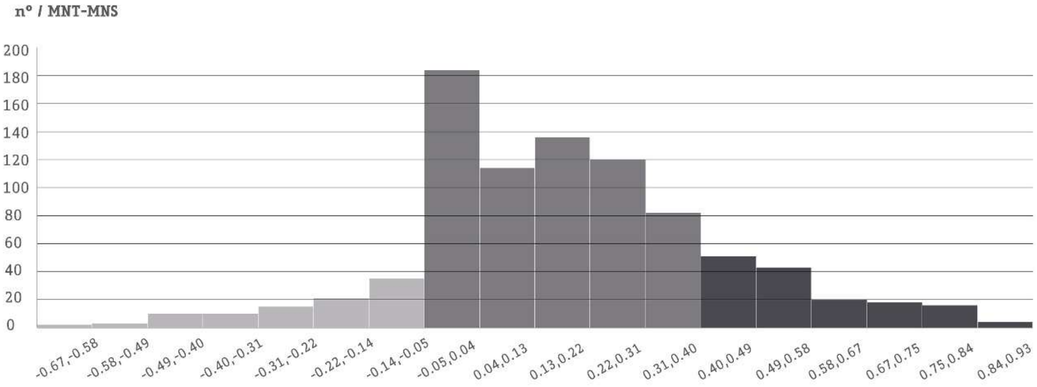
Figure 5 Visibility regions in DTM (A), DSM (B) and DTM-DSM (C), compared with land use map (D).

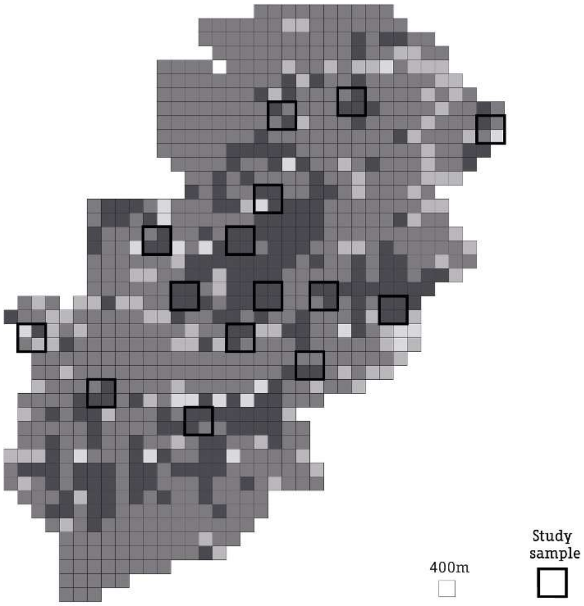
Figure 6 Photo survey's examples in relation to different environments, with specification of urban tissue (if any) and visibility types obtained from overlay by difference.



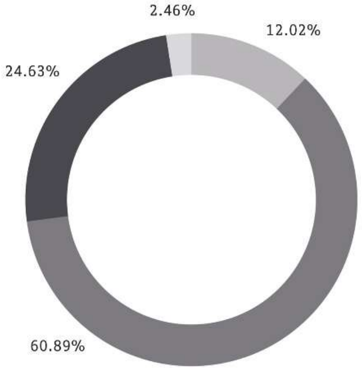

(b)
(a)
(ab)
(c)
(c)
DTM (viewpoints)
150
100
50
0
Amphitheatre
Escarpment
Terrace
Linear valley
Ramified valley
Geofacies
A
455
0
0
1.5km
B

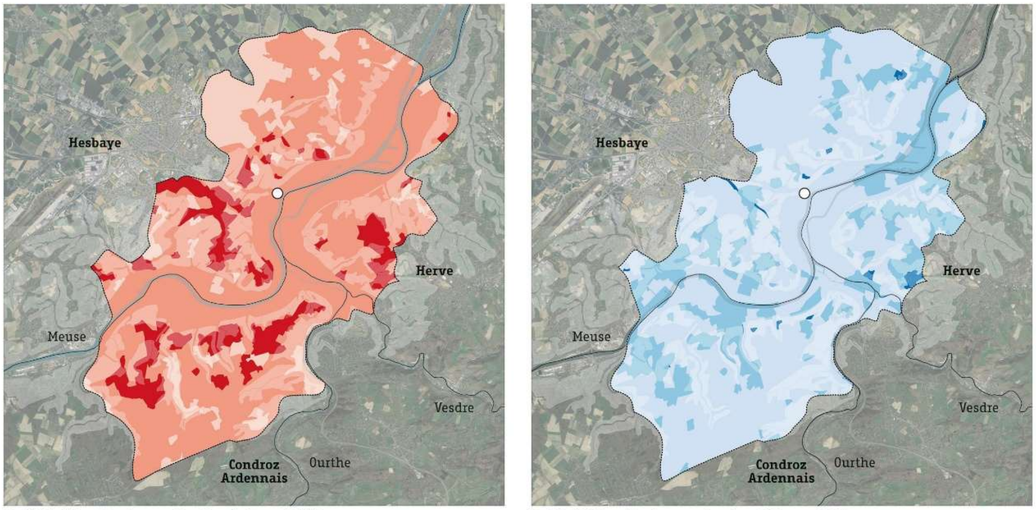

(c)
(b)
(c)
(c)
(a)
12
8
4
0
DSM (viewpoints)
Amphitheatre
Escarpment
Terrace
Linear valley
Ramified valley
Geofacies
A
B
106
0
0
1.5km





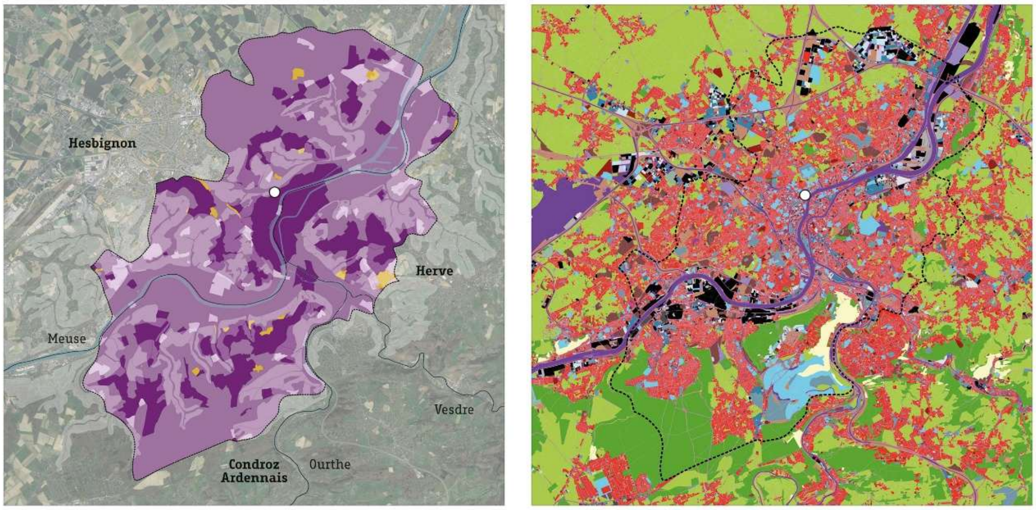
TYPE		Sup (ha)	%
A (DTM<DSM)	▒	-0.67, -0.049	12.02
B (DTM=DSM)	▓	-0.05, 0.39	60.89
C (DTM>DSM)	█	0.4, 0.93	24.63
NC (Not Classifiable)	░	/	2.46





A Visibility Regions obtained from DTM

B Visibility Regions obtained from DSM



C Visibility Regions obtained from overlay by difference

D Land use

○ **City Centre** 0 2km

Legend

A ● Low ● Medium ● High

B ● Low ● Medium ● High

C ● DTM<DSM ● DTM=DSM ● DTM>DSM ● Not Classifiable

D
- ● Agriculture
- ● Silviculture
- ● Extractive industries
- ● Fisheries and aquaculture
- ● Undefined secondary production
- ● Raw materials industry
- ● Heavy industry
- ● Light industry
- ● Energy production
- ● Business services
- ● Financial, specialized and information services
- ● Public services
- ● Cultural, leisure and recreational services
- ● Transport networks
- ● Logistics and warehousing services
- ● Public utility networks
- ● Permanent residential use
- ● Residential use with other compatible uses
- ● Other residential use
- ● Nature conservation
- ● Abandoned areas
- ● Unknown use

6 (NC)

Urban wasteland, Semi-continuous extension

17 (C)

Playground, Semi-continuous extension

18 (A)

Residential, Open in ribbon

135 (C)

Residential, Continuous ancient

240 (C)

Hospital, Semi-continuous extension

280 (C)

Residential, Continuous extension

324 (C)

Forest

434 (C)

Residential, Open in ribbon

499 (C)

Urban park

500 (NC)

Urban park

507 (C)

Urban park, Continuous extension

537 (C)

Square, Continuous extension

565 (B)

Residential, Semi-continuous extension

566 (C)

Residential, Semi-continuous extension

654 (B)

Square, Continuous extension

655 (C)

Natural reserve

692 (B)

Agricultural land

790 (C)

Residential , Continuous extension

791 (C)

Residential , Continuous extension

901 (C)

Cemetery