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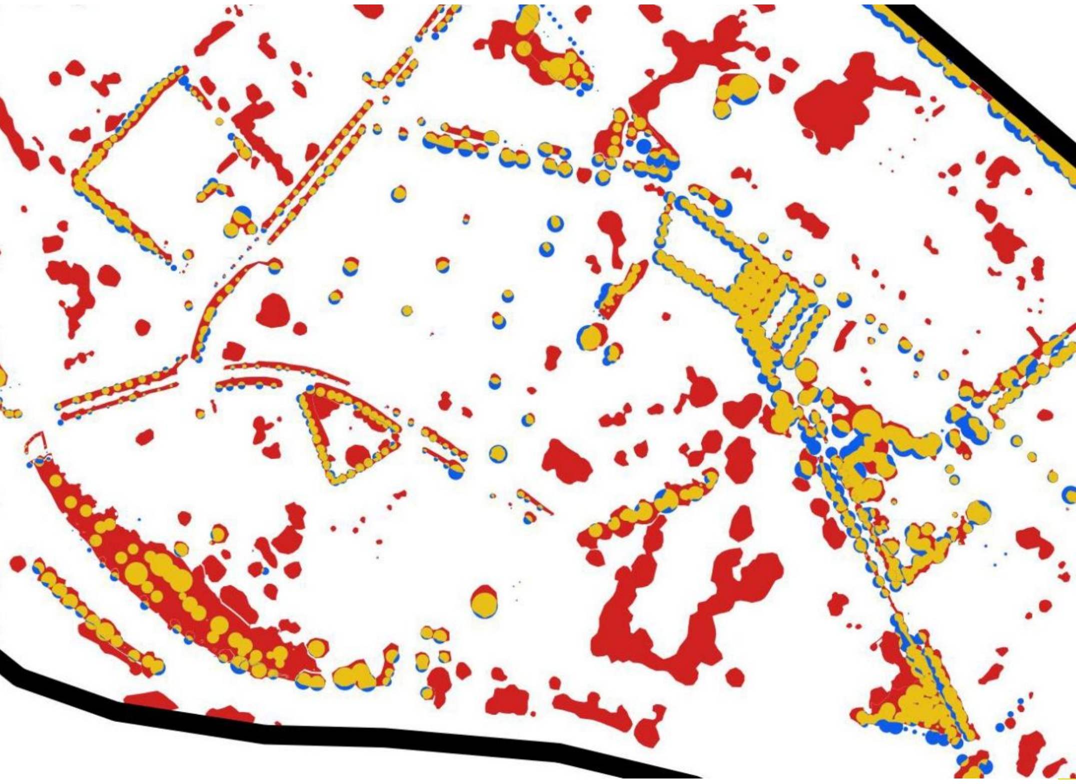
David J. Torne

Analyzing Urban Ecological Connectivity – A Comparative Study

Biodiverse Cities:
Social-ecological Studies in Bremen-Gröpelingen II

artec Paper Nr. 236
March 2025



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March 2025
ISSN 1613-4907

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1. Introduction

In 2024, over fifty percent of the human population lives in urban areas (*World Bank, 2023*). With this number only set to increase, it is important to understand and analyze how these environments can fracture and disrupt ecological communities but also harbor and conjoin them. Because of this, more and more research is being done on urban ecological connectivity (*Tischendorf & Fahrig, 2000; Vijayaraghavan, 2016; Casalegno et al., 2017*). Since this is a relatively new field, different methodologies and approaches are still in use. For this project, the approach used to measure ecological connectivity is the same used in several recent studies (*Casalegno et al., 2017; Von Thaden et al., 2021*). Urban ecological connectivity is centered around the connectivity of urban green spaces (UGS) since these spaces tend to be the areas within cities that harbor the most biodiversity and play a more crucial role on the ecology of urban areas (*Marulli & Mallarach, 2004; Du et al., 2017; Ramírez-Aguilar & Lucas Souza, 2019*). This focuses mainly on locating tree cover and then analyzing how well these areas with tree cover are connected to one another.

In our study in Gröpelingen, beginning with the data currently available to the state through its own systems (the GRIS system), we find data for each tree within public areas. This includes most notably: coordinates, tree height, crown radius, species and year of planting. Using the coordinates and crown radius, the tree cover for these trees can be established. However, this data does not include any information for the trees in private areas such as gardens that also constitute a large amount of the tree cover (*Torne, 2024*). Due to this shortcoming, two different methodologies proposed here attempt to locate the entire tree cover and analyze its connectivity.

Three methodologies are compared in this report, all of which focus mainly on tree cover.[1] For the purpose of our study, we call them the Visual methodology, the GRIS data methodology and the NDVI methodology. Satellite imagery was the main tool used, as for most studies on the topic (*Hancock et al., 2016; Choi et al., 2021; Morin et al., 2022*). Tree cover is usually measured by combining surface elevation data, usually Lidar, with NDVI data which determines where vegetation is present (*Casalegno et al., 2017; Da Rocha et al., 2017*). This methodology has many advantages since it only requires satellite data, which is preexistent in many cases. This allows for the study of large areas with relative ease. However, supplementing NDVI and Lidar data with other data sources can help researchers get a more complete picture of the multiple factors that influence ecological connectivity.

The two major factors determining the connectivity of a landscape are distance and the barrier effect(s). In urban settings, where the green spaces are smaller and more isolated, the barrier effect plays an oversized role. Previous research has attempted to quantify the barrier effect by classifying land uses on their permeability (*Marulli & Mallarch, 2004*). This project tries to overcome some of the shortcomings of previous research by combining different data sources and trying to analyze the barrier effect in a qualitative manner as well as in a quantitative manner. Satellite imagery and elevation data is still the basis of much of this analysis; However, building data and GRIS tree databases were also used and combined to provide a more complete picture of the situation.

[1] This report builds on an earlier project in which visual analysis was made (Torne, 2024). The first report provides additional context and background information and focuses on the identification and categorization of trees in the Bremen Lindenhof district.

Barrier effect(s)

The barrier effect refers to land use forms and structures obstructing the flow of energy, information or matter across the ecological matrix (*Marulli et al., 2004; Choi et al 2021*). This term is generally used to refer to the effect roads can have on vertebrate fauna such as dividing populations of mammals, yet the term can encompass more detailed scenarios. In McRae et al., (2012),e.g. we can see an example of an anthropogenic rural environment where walls can divert the movement of species.

Furthermore, not only the presence of anthropogenic elements can create barriers, but also the removal of natural elements. For example, in an area where a strip of grass connects two patches of trees, the removal of the grass to expand the pavement could discourage small insects from crossing. Unfortunately, not enough research has been done to analyze these small-scale examples of the barrier effect.

Surfaces matter

To provide a clearer example of this, we can compare a sidewalk with a grass-covered park. The sidewalk sees more people walking through it, it is cleaned regularly and is more likely to be narrow and adjacent to other "barrier heavy" areas such as roads and buildings. The grass is likely to provide cover for small walking arthropods such as ants and millipedes. The flowers attract pollinators such as bees and butterflies. Under the soil surface, worms and seeds are a source of food for many birds. The idea of analyzing the barrier effect not as a binary symptom but as a gradient of difficulty vs. ease of movement within the ecological matrix has also been used in previous studies such as *Marulli & Mallarch (2004*). Two out of the three methodologies we look at do not take into account the small changes in ecological connectivity that take place due to surface cover. By combining different sources of data we can better understand connectivity within a matrix as complex as urban environments, with numerous and diverse barrier effects.

Vegetation strata

Vegetation includes big elements such as trees that have a big impact on the structure and connectivity of the ecosystem, but also smaller elements such as grasses and bushes. These big elements of woody vegetation are the base of much of the ecological connectivity analysis (*Aronson et al., 2017; Von Thaden et al., 2021; Choi et al., 2021*). These elements are generally referred to as "trees", with different definitions. However, all vegetation plays a role and should be considered for ecological connectivity, not just the trees.

What are trees?

Studies such as Von Thaden et al (*2021; Barr et al., 2021*), make reference to woody vegetation or the "arboreal stage". For this project, we analyzed vegetation taller than 5 meters as "trees". This height was selected due to the FAO's definition of forest where the trees are at least 5 meters tall. In practical terms, this definition facilitates data processing since the elevation data is one of the main sources of data for this project, and a common datasource future projects can utilize. Other studies (*Li et al., 2017; Ganz et al., 2019; Morin et al., 2022*) also separate vegetation by height or type since it is faster and still portrays the ecological role the different vegetation strata play.

2. Materials and methods

All maps were generated using QGIS3 software (*QGIS.org, 2021*). For the *visual methodology*, the data presented in the earlier report (*Torne, 2024*) was used. We took raster images of the area from Google Earth Pro (*Google Earth Pro 7.3.6.9345, 2022*), and the trees were identified individually by contrasting the images with Google Maps, Google Earth and Google Street View to determine where the trees were located and to differentiate trees from bushes and other vegetation.

For the *GRIS methodology*, data were provided by Umweltbetrieb Bremen (UBB, the Bremen-owned company in charge of managing most public green spaces). These data were exported from their GRIS database as csv-files including coordinates, crown radius, height, year of planting and species. In total, over 225,000 trees were included of which only the trees within the two areas of study were selected and all others removed. Then a buffer was made from each point representing the radius of the respective tree. The measuring tool was used to ensure the buffers correctly represent the diameter present in the table for some trees as an example. Once the buffer has been verified, the areas were merged to create a single polygon showing the tree cover.

For the building data present in all maps, OpenStreetMap (OSM) data was used (*OpenStreetMap, 2024*). This is an open data source, freely accessible online. Since the data is community based, some of the data is incomplete and therefore some buildings' usage is unclassified. The same source was used for the data on roads.

For the *NDVI methodology*, all data was provided by GeoInfo Bremen[2]. Four different data types were provided: DOP (digital orthophotos), DOP-CIR (digital orthophotos with a near infrared channel), DGM (digital terrain model, a relief map of the ground surface) and DOM (digital surface model, a relief map including buildings, trees and anything else that may be found on the surface). The DOP and DOP-CIR were used to calculate the Normalized Difference Vegetation Index through the following formula:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

The NIR is the Near Infra-Red channel from the CIR file and Red is the red channel from the DOP file. With the raster calculator, this formula can be calculated and converted for output in a new file. This includes the NDVI value for each pixel, which then can be transformed into a vector file including all areas with an NDVI value higher than 0.25. The second calculation necessary is the height. The raster calculator is used again to subtract the ground height (DGM) from the digital surface model (DOM) to determine the height of all objects irrespective of the elevation of the ground below them. Then, for the areas within the NDVI polygon, a new polygon layer is created with all the vegetation areas with a height above 5 meters. The previous area delineated with an NDVI score above 0.25 is then divided into two, with an area above 5 meters in height and an area below 5 meters in height. These two areas represent trees (taller vegetation) and lower vegetation.

[2] We acknowledge the support of GeoInfo Bremen and thank Guido Mohaupt for his help in providing the data.

3. Results

The results are presented as maps: one map for each methodology, a map to compare the first two methodologies, three zoomed in maps of the NDVI methodology and a map of buildings uses.

Results based on GRIS methodology

Figure 1: Tree cover and building cover in the Industrial Park Riedemann-Reiherstraβe (left) and Gröpelingen Lindenhof (right) based on GRIS data. CRS: EPSG:3857. Data from GeoInfo Bremen

This methodology consists of using a database of each tree, their coordinate and diameter. In our case, the database was the Umweltbetrieb Bremen's GRIS database provided by GeoInfo Bremen

Results based on visual methodology

This visual methodology was used in the earlier report. By comparing publicly accessible 3D imagery with high quality rasters, the area of each tree can be manually traced and recorded into a geographical information software such as QGIS (QGIS.org, 2021).

Figure 2: Tree cover and buildings in Lindenhof district based on Visual data. Map by D.J. Torne with data from Google Earth Pro: EPSG:3857

Results based on NDVI methodology

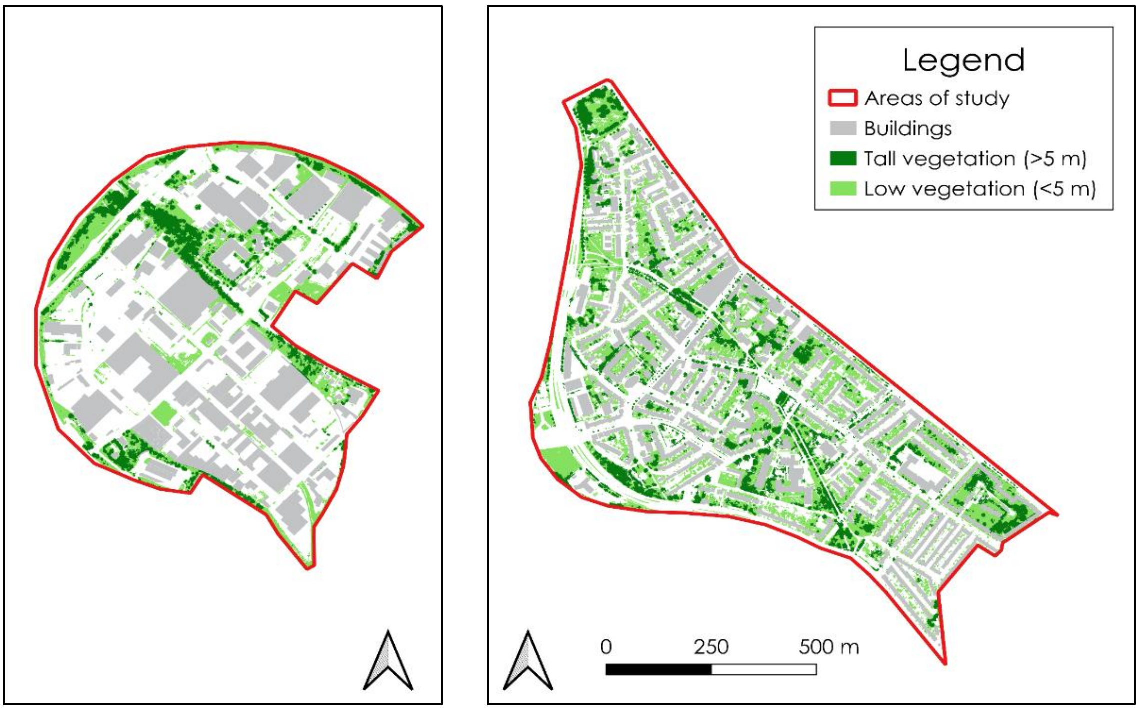

Figure 3: Vegetation cover and buildings in the Industrial Park (left) and Lindenhof district (right) based on NDVI methodology. Map by D.J. Torne with data from GeoInfo Bremen. CRS: EPSG:3857.

This methodology shows all areas with an NDVI value above 0.25 in green as vegetation. The dark green are the areas also above 5 meters in height, representing trees.

Visual and GRIS methodologies comparison

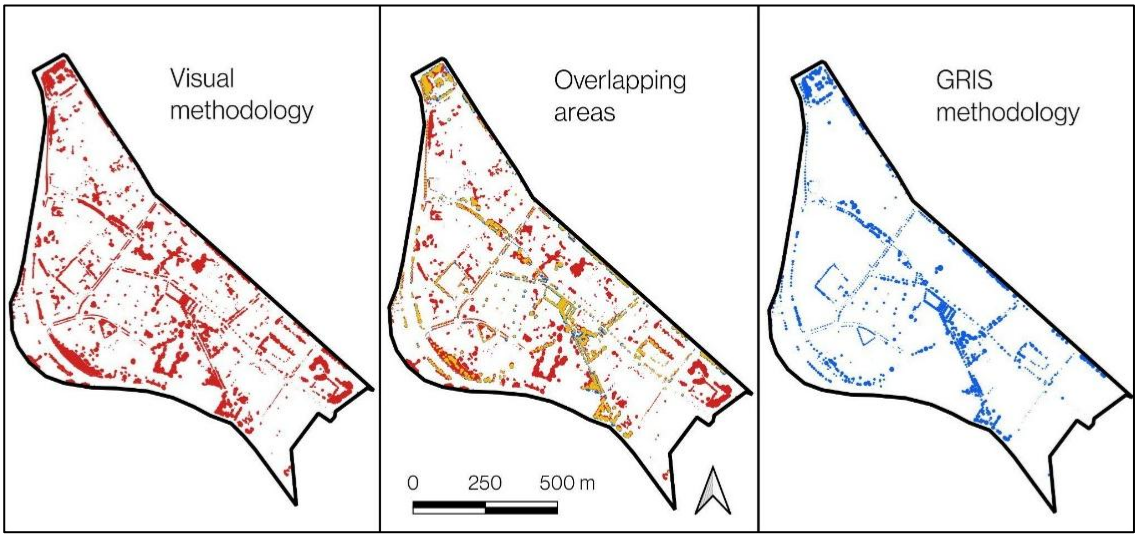

Figure 4: Comparison of the areas identified as trees by the visual methodology (red, left), GRIS methodology (blue, right), and their overlapping areas (orange, middle) in Lindenhof. CRS:3857. Data from Google Earth Pro and GeoInfo Bremen.

When comparing the two methodologies, it is clear that the areas identified as tree cover that are not overlapping are almost exclusively identified only by the visual methodology.

Built-up area

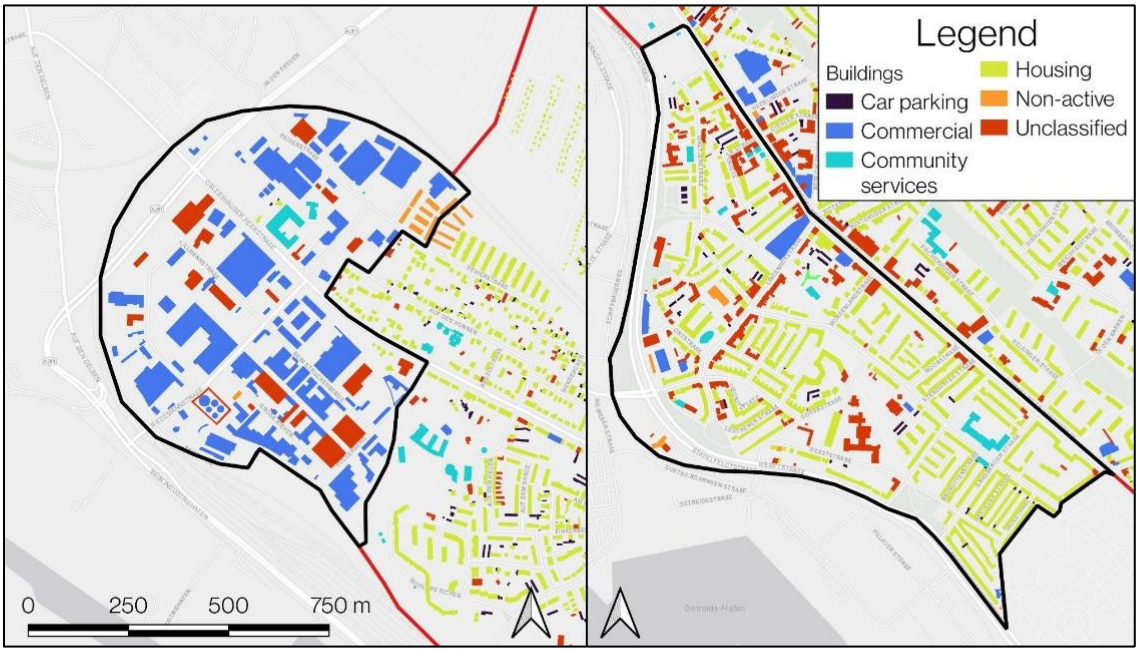

Figure 5: Built-up areas in the Industrial Park and Lindenhof. CRS:3857. Data from OSM.

Using OpenStreetMap data (*OpenStreetMap, 2024*), all present buildings are categorized into 5 categories depending on their land use. Buildings without data for their land use are left as unclassified. This map shows how the Industrial Park (left) mostly has Commercial buildings while Lindenhof (right) mostly has residential buildings.

Examples NDVI methodology – Zoom 1

Figure 6: First comparison, between NDVI map and satellite image in the northern edge of Lindenhof. CRS: EPSG:3857.

This map shows the Gröpelingen cemetery. The image on the left shows the results of the third methodology, on the right a Google image of the same area can help validate the accuracy of the third methodology.

Examples NDVI methodology – Zoom 2

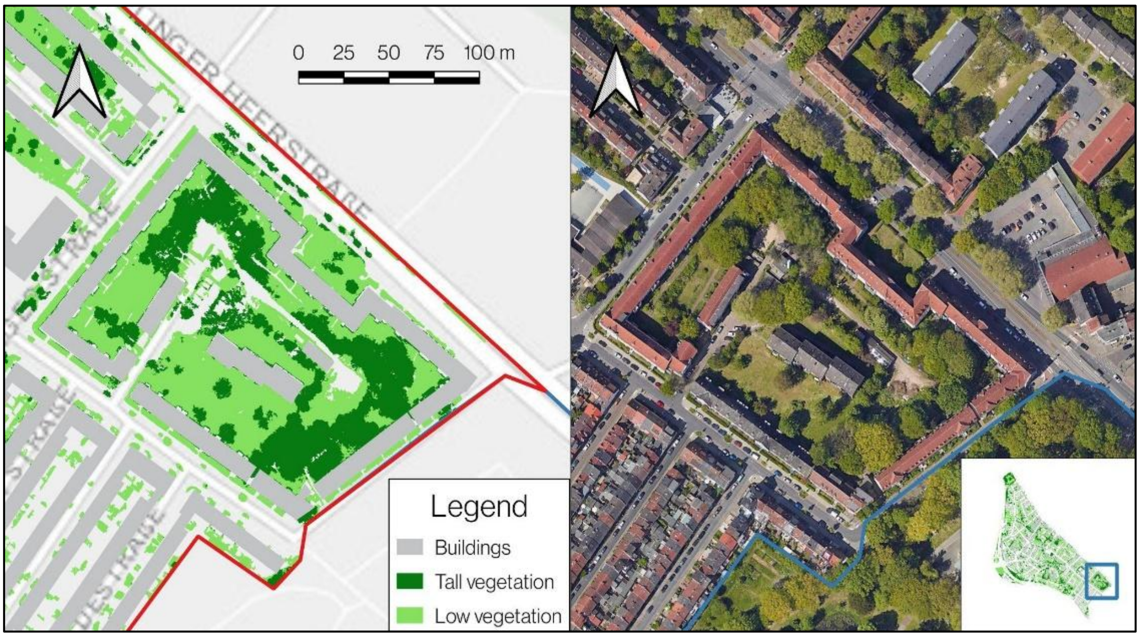

Figure 7: Second comparison, between NDVI map and satellite image in the south-eastern corner of Lindenhof (Pastorenweg/Altenescher Straβe). CRS:3857.

The second comparison (Fig. 7) shows an area on the south-eastern corner of Lindenhof. On this map we can see how the footpaths are clearly distinguished from the surrounding grass. However, the trees just to the north on the main road seem to be quite diminished in size. This is probably due to the road underneath reflecting light might have affected the NDVI values.

Examples NDVI methodology – Zoom 3

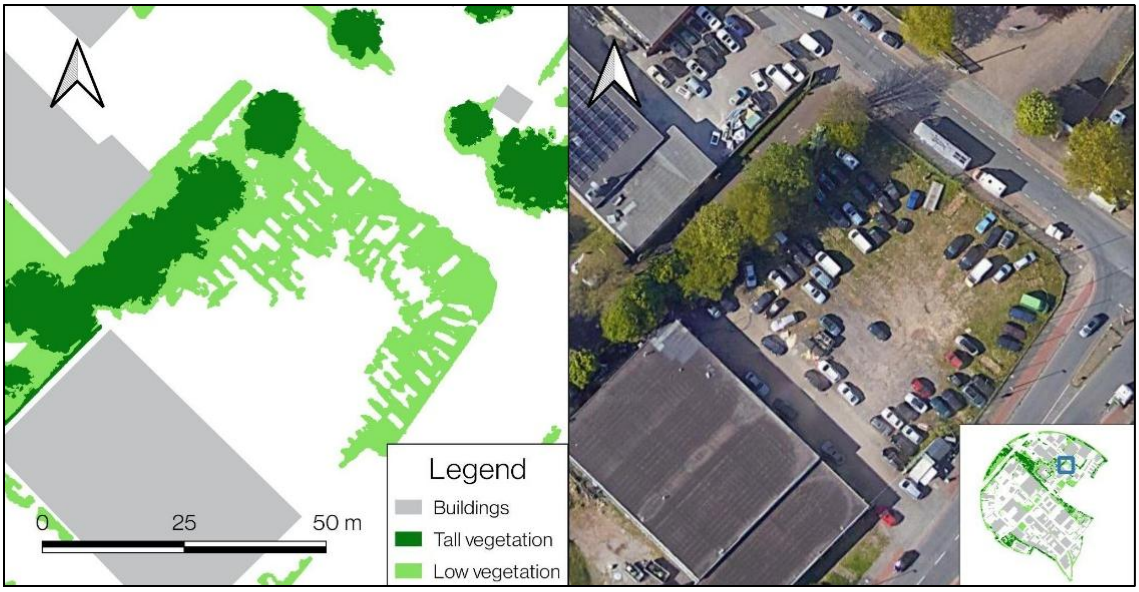

Figure 8: Third comparison, between NDVI map and satellite image in the north-eastern side of the Industrial Park. CRS:3857.

The last zoom (Fig. 8) shows a parking area in the Industrial Park. The grass has rectangular spots due to the cars parked on top.

4. Discussion

Gröpelingen-Lindenhof and the Industrial Park

The two areas show very different distributions of urban vegetation. On one side, the vegetation in Lindenhof consists mostly of small parks and rows of street trees. The vegetation is therefore very evenly distributed with few areas of concentration. On the other side, the Riedemann-/ Reiherstraβe Industrial Park has a few large areas with lots of trees separated by streets without trees. This means that both areas are subjected to different ecosystem pressures and likely host somewhat different communities (*Braaker et al., 2014; Jaganmohan et al., 2015; Mata et al., 2023,* see also the vegetation study by *Kalvelage 2024*).

The differences become more apparent when we look at the building data. The majority of the buildings in the Industrial Park are of commercial use while there are no residential buildings. By comparison, Lindenhof is mainly a residential neighborhood where most buildings are much smaller and closer together, with some house and front gardens inbetween. The main building use is housing, while some commercial and community service buildings are present. The differences in use, not only in the buildings but in the neighborhoods themselves, mean initiatives and proposals must take their different needs into account.

GRIS data methodology

For the entire city of Bremen, the GRIS dataset includes each street tree and public space tree, which accounts for over 225,000 trees. For each tree, it provides coordinates, crown radius, height, year of planting and species. This data is invaluable since it is the only methodology that provides us an insight into the age and species of each individual tree. Thus, studies focusing on a few specific species of trees may only use this methodology, since no other methodology includes this data. An important advantage of this methodology is its scalability. The time necessary to apply this methodology to an area is independent of the size of the area.

Yet there are also shortcomings with this dataset. The first one, is that it relies on a government body to maintain and continuously update the database. Luckily, in the case of Bremen, this is very well done. However, when applying this methodology to other areas of study, this cannot be assumed, so the quality of pre-existing data will be a factor to consider. The second and more important shortcoming is that the database is unlikely to include private trees. The reason for this is that the organizations that maintain the databases have no responsibility over the trees private individuals or businesses grow on their own land. In analyzing a completely self-enclosed green space such as a park, where every tree is likely to be part of the database, this is not a problem and this methodology is likely the best possible option. In the case of an urban space such as our case in Lindenhof and the Industrial Park, there is a large amount of trees in private gardens and backyards which can simply not be accounted for. Based on the data collected during the first report, we know that, for Lindenhof, these private trees account for 43% of the total tree cover.

Visual methodology

This methodology has some clear advantages: the information is freely available and the geoprocessing skills required are low. The resulting data is fairly accurate and includes all trees in the given area. The main disadvantage tof his methodology is its poor scalability. Since it requires manual analysis, any increase in area covered requires additional work proportional to the new area. This methodology also provides no information besides tree cover, since it does not include height or species data. Since this methodology requires a large amount of time, only one of the two focus areas, Lindenhof, has been analyzed with it. However, comparing the results of this methodology within Lindenhof can help us get a better perspective on how accurate this methodology is in comparison to the other two.

Comparison between GRIS and visual methodologies

Comparing the two methodologies, it is important to realize their differences can actually complement each other. When looking at the results of the comparison, it is clear that the areas identified as tree cover that are not overlapping are almost exclusively identified only by the visual methodology. This may seem to at first indicate that the visual methodology is more thorough, but it fails to capture the depth of the data the GRIS data methodology provides. As previously stated, the GRIS methodology excludes many trees that are present in urban areas with private UGSs. However, it provides age, species and height data that the visual method does not provide. Combining both methodologies can provide a complete knowledge of tree cover, and good estimates on size, species and age of all trees present, even if part of the tree cover does not include that data. In this sense, the GRIS data can be used to enrich the cover data provided by the visual method. This can be useful for understanding the area's ecological connectivity by providing information on the distance between different elements of the ecosystem. Unfortunately, this combination provides little information on the barrier effect. In most of the maps presented until now, the buildings have been included since this is usually the extent of analyzing the barrier effect, sometimes also including height (*McRae et al., 2012; Jaganmohan et al., 2015; Lee et al., 2022*). However, the third methodology combines multiple data sources and provides a more accurate picture for the barrier effect and therefore the ecological connectivity. There are three main reasons. The first one is that it analyzes the height of different elements. Two trees measuring 20 meters separated by a small hut measuring 7 meters do not face the same barrier as two trees measuring 7 meters separated by a building measuring 20 meters. The second reason is that by including open street map data (OSM), it provides a better understanding of the soil uses and therefore the ecological pressures each surface entails. Adding to this, the third reason is that this methodology includes all vegetation, not just trees. Despite trees being crucial for the structural connectivity of an ecosystem, grass cover for example, can provide much less of a barrier than asphalt or cobblestone for many organisms

Use of building data

The building data included in this project was mostly used simply to indicate the presence of obstacles. As previously mentioned, the barrier effect in these urban environments mostly consists of buildings. In all three methodology maps the buildings were simply added without information on their usage or height, and the map including building uses is presented separately. This data can be used in parallel to other maps however. For example, knowing which buildings are private residences or offices or public buildings can inform decision makers about where different measures would be easier or better to implement. Elevation data for the trees and buildings is also calculated since it could help in the future to observe if the buildings surrounding a tree are taller than the building itself, but not presented on any map. As an example, buildings taller than the surrounding trees would mean a bigger barrier effect than buildings shorter than the trees. Such nuance should be explored further but is beyond the scope of this project.

Additional information can always be added to such models to improve the system. Knowledge on road traffic or building use would also be helpful. Public buildings such as schools or hospitals might have an easier time implementing government initiatives such as green roofs as opposed to private residences where multiple private owners must be contacted individually.

NDVI data methodology

The NDVI model is the most complex of all the three compared here. It is based on the combination of the Normalized Difference Vegetation Index, which determines where there is vegetation, and the object height, which determines the height of said vegetation. Trees or tall vegetation are the most crucial areas of ecological connectivity. In short, these are the areas to be connected. Then lower vegetation represents areas that provide a small barrier effect and can still improve connectivity. Buildings constitute the highest barrier effect forming the biggest obstacle to connectivity, because of this, their location was also included. Lastly, the remaining area is generally different ground covers (pavement or roads) and smaller, often less permanent, barriers such as parked cars. This tiered approach can be helpful to address the barrier effect not as a binary issue but as a spectrum of transparency and ease of movement between areas. For example, large areas of low vegetation located near parks full of trees might not be suitable for projects if these two are separated by wide roads with lots of traffic. The road separation constitutes a major barrier when the vegetation to be connected is low, such as grass.

Additionally, by understanding what each area contains and not simply how much space divides them, more informed decisions can be taken. Wide streets with no trees that separate areas of abundant trees might be a better investment to plant trees than narrow streets connecting small parks.

Applications

The selection and application of a methodology, and the interpretation of its results for intervention and planning purposes are crucial preparatory steps for decision making. For example, from our resulting maps we can see the Lindenhof vegetation being composed of many small pockets with some rows of street trees composing smaller or larger corridors. These patches and corridors coexist in a complex matrix of smaller buildings separated by narrow streets. The Industrial Park vegetation has a completely different layout with bigger buildings and wider streets but where vegetation is concentrated in bigger areas standing further apart.

Because of this difference in characteristics in our two areas, initiatives for both areas should be approached differently. In Lindenhof, the green corridor that extends south from the Bürgermeister Ehlers-Platz could be expanded through the Eastern part of Geeststraße to connect to the much larger Friedhof Walle park, through a public or neighbor-encouraged initiative. On the other hand, the industrial buildings in the Industrial Park could be covered with green roof gardens to improve connectivity through a public-private initiative. These green roofs should always be placed in such a way that they help connect the existing urban green areas through corridors, stepping stones or strategic connecting nodes (*Mayrand & Clergeau., 2018; Shafique et al., 2018; Louis-Lucas et al., 2022*).

On a wider scale, we can see how the combination of NDVI and elevation data effectively shows where vegetation is present. Additionally, data not necessarily describing vegetation such as the presence of buildings and their heights, roads, traffic and bodies of water must also be taken into account because they determine the barrier effect. Acknowledging these two elements as spectrums is crucial for gaining a better understanding of the barrier effects and ecological connectivity. The difference between grass, bushes, young trees and old large trees in ecological connectivity should be considered just as relevant as the difference between small houses, large apartment buildings and shopping centers. With our study, we have shown that insight into matters of ecological connectivity can be improved in a systematic manner, based on widely available data and with acceptable effort.

Bibliography

Aronson, M. F., Lepczyk, C. A., Evans, K. L., Goddard, M. A., Lerman, S. B., MacIvor, J. S., Nilon, C. H., & Vargo, T. (2017). Biodiversity in the city: key challenges for urban green space management. Frontiers in Ecology and the Environment, 15(4), 189–196. https://doi.org/10.1002/fee.1480

Barr, A. E., Van Dijk, L. J., Hylander, K., & Tack, A. J. (2021). Local habitat factors and spatial connectivity jointly shape an urban insect community. Landscape and Urban Planning, 214, 104177. https://doi.org/10.1016/j.landurbplan.2021.104177

Braaker, S., Ghazoul, J., Obrist, M. K., & Moretti, M. (2013). Habitat connectivity shapes urban arthropod communities: the key role of green roofs. Ecology, 95(4), 1010–1021. https://doi.org/10.1890/13-0705.1

Casalegno, S., Anderson, K., Cox, D. T. C., Hancock, S., & Gaston, K. J. (2017). Ecological connectivity in the three-dimensional urban green volume using waveform airborne lidar. Scientific Reports, 7(1). https://doi.org/10.1038/srep45571

Choi, H., Song, Y., Kang, W., Thorne, J. H., Song, W., & Lee, D. K. (2021). LiDAR-derived three-dimensional ecological connectivity mapping for urban bird species. Landscape Ecology, 36(2), 581–599. https://doi.org/10.1007/s10980-020-01165-8

Da Rocha, N. A., De Sena, Í. S., Casagrande, P. B., De Castro, M. M., Fonseca, B. M., & Moura, A. C. M. (2018). STUDIES OF VOLUMETRIC RELATION BETWEEN VEGETATION AND BUILDINGS USING LIDAR DATA AND NDVI TO PROPOSE URBAN PARAMETERS. Revista Brasileira De Cartografia, 69(8). https://doi.org/10.14393/rbcv69n8-43974

Du, H., Cai, W., Xu, Y., Wang, Z., Wang, Y., & Cai, Y. (2017). Quantifying the cool island effects of urban green spaces using remote sensing Data. Urban Forestry & Urban Greening, 27, 24–31. https://doi.org/10.1016/j.ufug.2017.06.008

Donovan, G. H., Gatziolis, D., Jakstis, K., & Comess, S. (2019). The natural environment and birth outcomes: Comparting 3D exposure metrics derived from LiDAR to 2D metrics based on the normalized difference vegetation index. Health & Place, 57, 305–312. https://doi.org/10.1016/j.healthplace.2019.05.011

FAO *Forest*, *UNREDD Programme.* Available at: https://www.un-redd.org/glossary/forest#:~:text=A%20forest%20is%20an%20area,not%20the%20dominant%20land%20use (Accessed: 20 May 2024).

Ganz, S., Käber, Y., & Adler, P. (2019). Measuring Tree Height with Remote Sensing—A Comparison of Photogrammetric and LiDAR Data with Different Field Measurements. Forests, 10(8), 694. https://doi.org/10.3390/f10080694

Hancock, S., Anderson, K., Disney, M., & Gaston, K. J. (2016). Measurement of fine-spatial-resolution 3D vegetation structure with airborne waveform lidar: Calibration and validation with voxelised terrestrial lidar. Remote Sensing of Environment, 188, 37–50. https://doi.org/10.1016/j.rse.2016.10.041

Hashim, H., Latif, Z. A., & Adnan, N. A. (2019). URBAN VEGETATION CLASSIFICATION WITH NDVI THRESHOLD VALUE METHOD WITH VERY HIGH RESOLUTION (VHR) PLEIADES IMAGERY. the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences/International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-4/W16, 237–240. https://doi.org/10.5194/isprs-archives-xlii-4-w16-237-2019

Jaganmohan, M., Knapp, S., Buchmann, C. M., & Schwarz, N. (2015). The bigger, the better? The influence of urban green space design on cooling effects for residential areas. Journal of Environmental Quality, 45(1), 134–145. https://doi.org/10.2134/jeq2015.01.0062

Kalvelage, Lorena (2024): Urban flora: vegetation assessments in Gröpelingen and Oslebshausen, Bremen. In Flitner, Michael/Grimmig, Martina/Herbeck, Johannes/Segler, Sophia (eds.): Biodiverse Cities: Social-ecological studies in Bremen Gröpelingen (I). artec paper Nr. 232.

Lee, G., Kim, G., Min, G., Kim, M., Jung, S., Hwang, J., & Cho, S. (2022). Vegetation classification in urban areas by combining UAV-Based NDVI and thermal infrared image. Applied Sciences, 13(1), 515. https://doi.org/10.3390/app13010515

Li, F., Song, G., Liujun, Z., Yanan, Z., & Di, L. (2017). Urban vegetation phenology analysis using high spatio-temporal NDVI time series. Urban Forestry & Urban Greening, 25, 43–57. https://doi.org/10.1016/j.ufug.2017.05.001

Louis-Lucas, T., Clauzel, C., Mayrand, F., Clergeau, P., & Machon, N. (2022). Role of green roofs in urban connectivity, an exploratory approach using landscape graphs in the city of Paris, France. Urban Forestry & Urban Greening, 78, 127765. https://doi.org/10.1016/j.ufug.2022.127765

Marulli, J. and Mallarch, J.M. (2005) 'A GIS methodology for assessing ecological connectivity: Application to the Barcelona Metropolitan Area', *Landscape and Urban Planning*, 71(2–4), pp. 243–262. doi:10.1016/s0169-2046(04)00079-9.

Mata, L., Hahs, A. K., Palma, E., Backstrom, A., Johnston, N., King, T., Olson, A. R., Renowden, C., Smith, T. R., Vogel, B., & Ward, S. (2023). Large positive ecological changes of small urban greening actions. Ecological Solutions and Evidence, 4(3). https://doi.org/10.1002/2688-8319.12259

Mayrand, F., & Clergeau, P. (2018). Green roofs and green walls for biodiversity conservation: a contribution to urban connectivity? Sustainability, 10(4), 985. https://doi.org/10.3390/su10040985

McRae, B.H. *et al.* (2012) 'Where to restore ecological connectivity? detecting barriers and quantifying restoration benefits', *PLoS ONE*, 7(12). doi:10.1371/journal.pone.0052604.

Morin, E., Herrault, P., Guinard, Y., Grandjean, F., & Bech, N. (2022). The promising combination of a remote sensing approach and landscape connectivity modelling at a fine scale in urban planning. Ecological Indicators, 139, 108930. https://doi.org/10.1016/j.ecolind.2022.108930

OpenStreetMap Copyright and license. Available at: https://www.openstreetmap.org/copyright (Accessed: 20 May 2024).

QGIS Development Team, 2021. QGIS Geographic Information System. Open Source Geospatial Foundation. URL: http://qgis.org/

Ramírez-Aguilar, E. A., & Souza, L. C. L. (2019). Urban form and population density: Influences on Urban Heat Island intensities in Bogotá, Colombia. Urban Climate, 29, 100497. https://doi.org/10.1016/j.uclim.2019.100497

Shafique, M., Kim, R., & Rafiq, M. (2018). Green roof benefits, opportunities and challenges – A review. Renewable and Sustainable Energy Reviews, 90, 757–773. https://doi.org/10.1016/j.rser.2018.04.006

Tischendorf, L., & Fahrig, L. (2000). On the usage and measurement of landscape connectivity. Oikos, 90(1), 7–19. https://doi.org/10.1034/j.1600-0706.2000.900102.x

Torne, David J. (2024): Urban tree connectivity in the Lindenhof district of Bremen: An overview and proposal for the current analysis of urban trees. In Flitner, Michael/Grimmig, Martina/Herbeck, Johannes/Segler, Sophia (eds.): Biodiverse Cities: Social-ecological studies in Bremen Gröpelingen (I). artec paper Nr. 232.

Vijayaraghavan, K. (2016). Green roofs: A critical review on the role of components, benefits, limitations and trends. Renewable and Sustainable Energy Reviews, 57, 740–752. https://doi.org/10.1016/j.rser.2015.12.119

Von Thaden, J., Badillo-Montaño, R., Lira-Noriega, A., García-Ramírez, A., Benítez, G., Equihua, M., Looker, N., & Pérez-Maqueo, O. (2021). Contributions of green spaces and isolated trees to landscape connectivity in an urban landscape. Urban Forestry & Urban Greening, 64, 127277. https://doi.org/10.1016/j.ufug.2021.127277

World Bank Overview (2023). Available at: https://www.worldbank.org/en/topic/urbandevelopment/overview#:~:text=Globally%2C%20over%2050%25%20of%20the,1.5%20times%20to%206%20billion.

Zipperer, W. C., Wu, J., Pouyat, R. V., & Pickett, S. T. A. (2000). The application of ecological principles to urban and urbanizing landscapes. Ecological Applications, 10(3), 685. https://doi.org/10.2307/2641038

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Further information on the project and map files available on request.

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Co-funded by the European Union

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Editor
artec Sustainability Research Center, March 2025