International Journal of Strategic Property Management
ISSN: 1648-715X / eISSN: 1648-9179
2022 Volume 26 Issue 4: 287–304
https://doi.org/10.3846/ijspm.2022.17754

QUANTITATIVE VIEW ASSESSMENT (QUVIAS) METHOD FOR WINDOW VISIBILITY ANALYSIS UTILIZING BIM, GIS AND WEB ENVIRONMENTS

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Received 25 February 2022; accepted 03 October 2022

Abstract. The developers of the construction project assess the economic feasibility of the project at the early stages of project development and analyse possible alternative solutions. This research focuses on the assessment of property attractiveness and building location problems at an early stage of project development and proposes the original method for visibility analysis based on the utilization of Building Information Modelling (BIM), Geographic Information System (GIS) and Web environments. The proposed Quantitative View Assessment (QUVIAS) method allows to assess the view mathematically and presents it as a quantitative parameter. The proposed method considers the mathematical shape of the view as a sphere and utilizes spherical coordinates that remove distortions and increase the accuracy of the analysis. The presented approach determines quantitative view coefficients for alternatives of windows, premises and buildings, including their comparison. The way of determining the view proposed in the QUVIAS method can help decision-makers to make more accurate decisions during the selection of a project development strategy. The experimental analysis proved the usefulness of the proposed QUVIAS method in the assessment of the rational building location and prediction of project revenues as well as potential usefulness in the estimation of property attractiveness.

Keywords: Building Information Modelling (BIM), GIS, Web, QUVIAS, project planning, building location, visibility analysis.

Introduction

A building throughout its entire life passes through several phases: planning, designing, construction and operation. The full set of phases is called the building lifecycle, where each phase consists of different stages, analysed with various building delivery activities, events, and processes. However, one of the procedures that take place in all the flow of activities within project duration is the economic assessment of project solutions, like construction cost estimation, project payback period or premise selling price prediction. To justify the costs associated with the introduction of a new project, the benefits have to be quantified (Bauer & Craig, 2008). The prediction of costs and benefits has a different purpose. Examples are purchases, sales reports, accounting purposes, loan security, insurance, taxation and investments (Pagourtzi et al., 2003).

An accurate price assessment is important for investors for better decision-making in obtaining investment opportunities and avoiding risks (Nejad et al., 2017). One of the main procedures that can predict the final project income is called property valuation or property price prediction (Binoy et al., 2020). Based on the International Valuation Standards (IVS) the main aim of the property valuation is to make a prognosis of the selling price of the property for the date the property is going to be sold (International Valuation Standards Council, 2022).

Multiple methods and tools for property valuation exist (Pagourtzi et al., 2003) that are used by experts for the commercial and residential types of buildings. The multiple-criteria decision-making analysis (MCDA) (Antucheviciene et al., 2015) is frequently involved in property valuation and price prediction. The most commonly used parameters (criteria) for the property valuation and price prediction defined by IVS and authors in their articles are building age, the number of rooms, floor area, lot size, property location, view, distance to the points of interest such as public transport, shops, subway (Sirmans et al., 2005; Ja'afar et al., 2021; Chen et al., 2020). The location of the building is considered a parameter that has a strong influence on the price of the premise (Schläpfer et al., 2015). According to the WELL building standard (International WELL Building Institute, 2022) one of the

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most important factors of the surrounding is a view. The importance of the view that can be seen from the window was proven by many researches (Zavadskas et al., 2021; Kaklauskas et al., 2007; Maliene, 2011; Jegelavičiūtė, 2017; Baušys et al., 2020). The WELL building standard and scientific articles that can be found in state-of-the-art consider the window view criterion as a qualitative parameter presented by linguistic grades or by points.

At this point, the discussion is not related to the sides of the world where the windows of the premise are located, but with a specific view from the windows. The view from the windows can influence the property attractiveness and property value in the spread of 1–57% (Baranzini & Schaerer, 2011). This is important for assessing the rational location of the building, which affects the project cost estimation. For example, the apartments with windows directed to the side of the highway or nearby buildings will always be cheaper in comparison to the same apartments with windows directed to the green areas or sea views.

As has been described above, the determination of the most rational price of the property involves a big set of data, such as real estate sales records data, cadaster land data, multilevel administration data and building data (Yu et al., 2014). However, assessment of the view involves on-site measurements, which are not possible to perform at an early stage of the construction project. To solve this gap Geographic Information System (GIS) is involved due to its higher accuracy and low human factors (Kara et al., 2020). GIS environment allows analysing of the 3D information in the real-world representation model such as the 3D mesh model (Laga et al., 2018).

Visibility analysis (Sirmans et al., 2005) is one of the most used GIS analyses to determine the view from the windows of the building. For the visibility analysis, multiple methods are used (Bourassa et al., 2004), which are the line-of-sight method (Yu et al., 2007), viewshed method (Lagner et al., 2018) and view dome method (Othman et al., 2019). Wrozynski et al. (2020) proposed one more method for visibility analysis which is Quantitative Landscape Assessment (QLA360). Yet, all of the existing methods have drawbacks.

The line-of-sight method does not allow analysing part of the view that is free from any objects, i.e. points can be placed on each object manually, but it is impossible to locate points in free space with equal distance between them. In addition, such an approach requires weeks of work to perform analysis for a single window. Therefore, it is not worth using it in real projects. The viewshed and view dome methods are based on Boolean variables (Lagner et al., 2018), therefore they do not consider the distance to the objects that influence the accuracy of the analysis. Additionally, the viewshed method is capable to analyse 180-degree areas both horizontally and vertically, however, the view is considered as plane geometry. Therefore, the calculations involve the transformation of the mathematical shape of the view which decreases the accuracy. In the QLA360 method, the mathematical shape of the view is considered as plane geometry as well. Moreover, line-of-sight and QLA360 methods can not specify the points on the surface of the mathematical shape of the view evenly since they do not involve spherical coordinates, which influences the accuracy of the calculation. Separately should be highlighted, that just the QLA360 method was designed for the determination of the view as a quantitative parameter that is required in multi-criteria analysis, whereas other methods provide composite parameters as a result.

Concluding the observations above, the view is considered as a qualitative parameter which has a high significance in property price prediction. However, existing methods are not fully applicable for the assessment of window view since none of them can calculate the view as a quantitative parameter considering the spherical nature of the view involving distances. Mainly, the experts use the results of the analysis mentioned above to assess the situation and based on such estimations, perform assessment of property price. However, this leads to a large volume of work, and experts are prone to subjective judgements.

To fill the highlighted gaps, this article aims to expand the estimation process related to the assessment of property attractiveness and building location problems by proposing an original method for window visibility analysis. The proposed Quantitative View Assessment (QUVIAS) method for window visibility analysis allows assess the view from the windows and determines quantitative view coefficients of the windows, premises and buildings alternatives. The proposed methodology integrates the BIM, GIS and Web environments (Shkundalov & Vilutienė, 2021) allowing to perform the analysis not just on already constructed buildings but on the planning stage of the construction project having the BIM model of a building. Such integration allows to improve the decision-making on the planning stage of the project and determine the rational location of the building more accurately.

The present article contributes to the field:

1. In raising awareness of approaches and methods for visibility analysis.
2. By proposing the quantitative view assessment method for visibility analysis that can be included in the multi-criteria analysis for solving property price prediction and building location problems.
3. By employing the QUVIAS method in window visibility analysis to determine the rational location of a building.

The remainder of the manuscript is organized as follows: Section 1 presents the literature review of scientific articles related to the topic of the research. Section 2 describes the proposed methodology used in the research. Section 3 presents the testing of the developed methodology on a case study. Section 4 provides a discussion of the findings of the research. Conclusions summarize the results of the research.

1. Previous studies

One of the first researches that can be found about visibility analysis in the context of property price prediction is dated 1998 and was carried out by Lake, Lovett, Bateman and Langford (Lake et al., 1998). In this research, Digital Elevation Model (DEM) and orthophoto mapped on it were used, which allowed visualizing 3D data in the content of the city. The main contribution of the presented methodology is that it allowed to analyse the data about the surrounding environment provided as GIS data and does not require any data to be collected on-site. According to the manuscript, the amount of work, as well as time consumption, dramatically decreased. Additionally, the authors concluded that the visibility of the objects in the view influences the selling price of a property.

Baranzini and Schaerer (2011) have examined the influence of the view on the rent price and estimated that the price could rise by 57%. However, some researchers highlight that the impact of view from the window on property selling price could be less significant (Lake et al., 2000). There is no common opinion on the influence of the view from the window on the attractiveness of the property due to differences in methods, study areas, years and locations (Sander & Polasky, 2009). Nonetheless, multiple researchers (Hamilton & Morgan, 2010; Jim & Chen, 2006; Lutzenhiser & Netusil, 2001; Bond et al., 2002) have proven that buildings with a scenic view are more attractive in the urban context.

The analysis of the state-of-art related to the visibility analysis shows that most of the researches investigate the influence on the view by:

- Ocean – the impact on the attractiveness of the property can be increased up to 60% (Benson et al., 1998);
- Rivers and lakes – the average impact on the attractiveness of the property is 7% (Wen et al., 2017);
- Green areas – mainly are related to parks and forests, the impact on the attractiveness of the property is 3–5% (Tyrvainen, 1997; Crompton & Nicholls, 2019);
- Other – mainly includes mountains, historical monuments and city attractions – can impact the attractiveness of the property by 6.7% (Jim & Chen, 2009, 2010).

According to the presented analysis, the view may have a big influence on the premise attractiveness and price as consequence. Such observation proves the conclusion made by Baranzini and Schaerer (2011).

Before 3D GIS technology became in use for property assessment, dummy variables were used (Yamagata et al., 2016). Most of the examined researches used a single dummy variable to determine the impact of view, where the view from the windows is assessed in points as 0 or 1. Nonetheless, some of the researchers (Jim & Chen, 2006) (Benson et al., 1998) used several dummy variables to determine the quality of the view. Studies that are based on 3D GIS are using visibility analysis, where the main methods (tools) for visibility analysis are viewshed and line-of-sight (Yang et al., 2007).

The algorithm of the viewshed method is based on the Boolean representation of the view (Lagner et al., 2018). The following rule is applied: in case the area is not visible from the observation point, the related part of the view is marked with a value of 0, while a value of 1 indicates that the area is visible. Such calculation of visible and invisible parts of the view does not rely on the distances to the object which leads to inaccuracies since the obstacles (buildings, trees, etc.) can be located far away from the observation point, but the analysis will return simply 0. The viewshed method allows analysing the view both horizontally and vertically by defining relevant angles, however, the mathematical shape of the view is considered as plane geometry.

The line-of-sight method builds lines from one point to another and detects the intersection of these lines with objects presented in 3D space. Hamilton and Morgan (2010) presented the approach based on the line-of-sight analysis with the angle ranging from 0 to 180 degrees. This approach can analyse the view more accurately compared to the viewshed analysis because the distance to the objects can be defined more precisely. However, it is impossible to place the points in free space. Therefore, the line-of-sight does not allow analysing the full view. Besides, the presented method analyse the view as one flat horizontal plane. The results of such analysis can represent the view related to some specific object, for example, a river or forest. However, it cannot inspect full view by default, i.e. horizontally and vertically.

Trigaux et al. (2015) calculated the visible parts of the sky using line-of-sight analysis. The main advantage of the proposed method is that it considers the view as a sphere and allows presenting the view as a quantitative parameter. For the calculation, the sky dome was subdivided into 3600 surfaces with equal area. For each surface, a line was built between the window and the centre of the surface. The visibility of the sky dome was calculated by the division of the number of lines without intersections and a total number of lines. The presented method calculates a percentage of the visible sky dome in the same way, as it is calculated in Esri ArcGIS solution view dome analysis (Othman et al., 2019), specifically, a method based on Boolean values and does not include distances to the objects of the real world. Another issue of this method is that the distances between the points on the dome surface are different, therefore the visibility cannot be calculated precisely. Additionally, the authors did not use the BIM model that influence the accuracy of the analysis.

The Quantitative Landscape Assessment (QLA360) method proposed by Wrozynski et al. (2020) allows to perform the quantitative landscape assessment based on LiDAR data utilising ArcGIS and Blender software. Although this research is not related to BIM technologies or real estate, the method proposed in this article considers the view as a sphere and presents it as a quantitative parameter. In this research, the view is presented as a 360-degree photograph. However, the proposed methodology does not calculate the distance to the objects. Another issue of the proposed method is that it uses the transformation of a 360-photo into a plane (2D) photo. Such transformation leads to distortions (Kerkovits, 2020) and inaccuracies in the calculations, and reduces the significance of the proposed method. Additionally, the presented approach is not related to the BIM environment or property price prediction. Nevertheless, the importance of the spherical nature of the view was highlighted and adopted in the proposed approach.

There is one more method for visibility analysis named view dome (viewsphere) (Othman et al., 2019). This method considers the mathematical shape of the view as a sphere which allows calculation of the view in both directions, i.e. horizontally and vertically. However, this method performs Boolean calculations similarly to the viewshed analysis that does not consider the distance to the objects (Yang et al., 2007).

The view has spherical nature and can hardly be presented by a figure with corners because the position of the points will be corrupted on corners. Such corruption is well researched in the GIS environment and is related to distortions of projections (Kerkovits, 2020). However, apart from the viewsphere method, all methods consider the mathematical shape of view as plane shape or calculations involves shape transformation. The studies that are based on the viewshed method does not involve distance parameter in calculations. On the other side, in the approaches that use the line-of-sight method the distance between ending points on the surface of the mathematical representation of the view is not even due to distortions.

Concluding the discussion above, there is no solution or method that allows analysing the view from the window horizontally and vertically and presenting it as a quantitative parameter based on distances and utilising spherical coordinates. Even professional solutions such as ESRI ArcGIS Pro cannot calculate visibility for properties located at different heights such as apartments (Oud, 2017). Moreover, most of the examined researches used visibility analysis based on GIS and BIM technologies to solve property price prediction problems. However, there were not found researches that would utilise the same technologies to solve the alternative building location problem.

This research increases the knowledge by proposing a QUVIAS (Quantitative View Assessment) method for window visibility analysis that allows calculating the view mathematically and presenting it as a quantitative parameter. The results of the study demonstrate how the integration of BIM, GIS and Web environments can improve the assessment of the property attractiveness and selection of rational building location. Additionally, the proposed approach can help the construction project developers and investors to make accurate decisions in an uncertain environment at an early stage of project development as well as can be sufficient in the real estate market.

2. Methodology

To analyse the visibility from the window in the condition of 3D real-world representation the view from the window has to be calculated mathematically. For this purpose, the view needs to be presented in some mathematically expressed shape that can be analysed. Since the distance parameter is important in property price prediction, two important conditions were defined.

The first condition states that the distance from the observation point to all points of the mathematically expressed shape that is used for view representation must be the same. From this condition can be concluded, that the mathematically expressed shape of the view should be considered as a sphere of 360 degrees, where the distance from the centre of the sphere to any point on the sphere's surface is the same.

In existing methods described in Section 1, the view is considered as a plane, and the distance between the ending points on a shape flattened on the sphere is not equal. Therefore, if to inspect a resulting shape with points placed on its surface, the result will be a square or irregular figure. An irregular figure cannot describe the view accurately, therefore it is not applicable. The distance from the observation point to the points on the square surface is never the same. To solve this problem the square needs to be flattened on the sphere, however, such operation leads to projection distortions where the distance between the points will be different which highly increases the inaccuracy of results (Kerkovits, 2020). This leads to the second condition that must be met for accurate calculations: the distance between the points on the mathematical shape must be the same.

The QUVIAS method proposed by the authors of this paper considers the view as a sphere that allows introducing spherical coordinates and removes aberrations that appear on corners of the plane flattened on the sphere. Another important difference between the QUVIAS method and existing methods is that the spherical approach allows ensuring an equal distance not just from the observation point to the points on the mathematical shape (sphere), but between the points on a sphere as well, where the distance parameter is involved into calculations. The developed method does not require a transformation of the mathematical shape. The comparison of the existing methods and the proposed QUVIAS method is presented in Table 1. Column "method name" contains the names of the methods, the "distance" column describes the usage of distance parameter in a certain method, "clear view" represents an ability to calculate the percentage of the clear view based on Boolean variables, "landscape area" describes the ability to calculate the percentage and area of the landscape clear from obstacles, and "shape accuracy" describes the need of mathematical shape transformation, such as sphere into a square.

The QUVIAS method considers the view as a sphere and does not require shape transformation, therefore the projection distortions are not influencing the calculation. This method allows calculating the clear part of the view and area of the landscape. Since the QUVIAS method determines the distance to the objects, the part of the view that is between the observation point and the object is

Table 1. Existing methods for window visibility analysis

Method name	Distance	Clear view	Landscape area	Shape accuracy
QUVIAS (proposed by the authors)	+	+	+	+
View dome (Othman et al., 2019)	–	+	+	+
QLA360 (Wrozynski et al., 2020)	–	+	+	–
Viewshed (Travis et al., 1975)	–	–	+	–
Line-of-sight (Jenkins & Hilkert, 1989)	+	–	–	Not applicable

included in the analysis calculations which improves the accuracy of the analysis.

The view dome method (Othman et al., 2019) allows to calculate the clear part of the view and considers the view as a sphere that does not require transformation. This method allows calculating the area of the landscape as well. However, this method does not involve the distance parameter in the calculations but determines the area based on Boolean variables. Mainly this analysis was designed for surface area calculation.

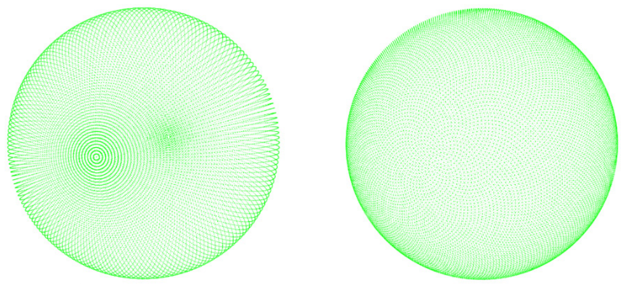
The QLA360 method (Wrozynski et al., 2020) allows determining the clear part of the view as well as the landscape area that does not have obstacles. This method considers the spherical nature of the view and allows to analyse a 360-degree image. However, the calculations presented in the original research require shape transformation that leads to projection distortions. Moreover, the QLA360 method does not involve a distance parameter and is based on Boolean values.

The viewshed method (Zhou et al., 2008; Petrasova et al., 2015) is dedicated to calculate the landscape area. The shape of the required part of the view for the analysis can be defined by angles both horizontally and vertically, however, the calculations are based on the utilisation of plane geometry, therefore transformation of the geometry is required. This method does not determine the distance to the objects, therefore the part of the view that is between the observation point and objects cannot be included into the calculation.

The line-of-sight method (Liu et al., 2010) cannot be used for view calculations since it does not allow to calculate the spherical shape at both horizontal and vertical angles. This method is not designed for any kind of area calculations. Nevertheless, it allows determining the distance to the objects from an observation point which is highly important in the view analysis. However, line-of-sight does not allow to calculate the part of the view that is free from objects.

The comparison of the methods reveals, that the distance is considered only in two methods: QUVIAS and line-of-sight. Since the distance is one of the most important parameters as was described in the previous section, view dome, QLA360 and viewshed methods have less accuracy because they use Boolean calculations. The comparison of the visibility analysis calculated using Boolean values and analysis based on distance parameters is presented and discussed in the next section. However, line-of-sight is not applicable for view visibility analysis since it does not allow to calculate the sphere shape. Moreover, just view dome and QUVIAS methods consider the spherical nature of the view which removes transformations and increases the accuracy as consequence.

Concluding this comparison, only the QUVIAS method allows to perform an accurate view visibility analysis since it involves distance-based calculations and considered the view as a sphere that does not require any transformation. To analyse the shape accuracy the difference between the transformed (square flattened on the sphere) (Figure 1a) and spherical shape (Figure 1b) that is used in the QUVIAS method need to be discussed.



a) b)

Figure 1. The difference between view representation as: a – square shape flattened on the sphere; b – spherical shape

From Figure 1 can be seen, that the distance between the points will never be equal if the mathematical shape of the view is considered as a plane geometry such as in the viewshed method. Multiple points that have the same position on the sphere surface (illustrated in Figure 1a) represent the corners of the square. On the other side, the spherical representation of the view consists of the points that have equal distance between each other. Such a uniform scatter of the points shows that the calculations are valid not only for the part of the view but also for the entire mathematical shape.

The proposed method includes the steps presented in Figure 2.

The Scheme presented in Figure 2 depicts the steps required to perform the analysis.

In step 1, the step angle that defines the distance between the points that will be built on the surface of the spherical shape must be defined.

In step 2, the set of windows for the analysis needs to be defined. The size of the set depends on the type of

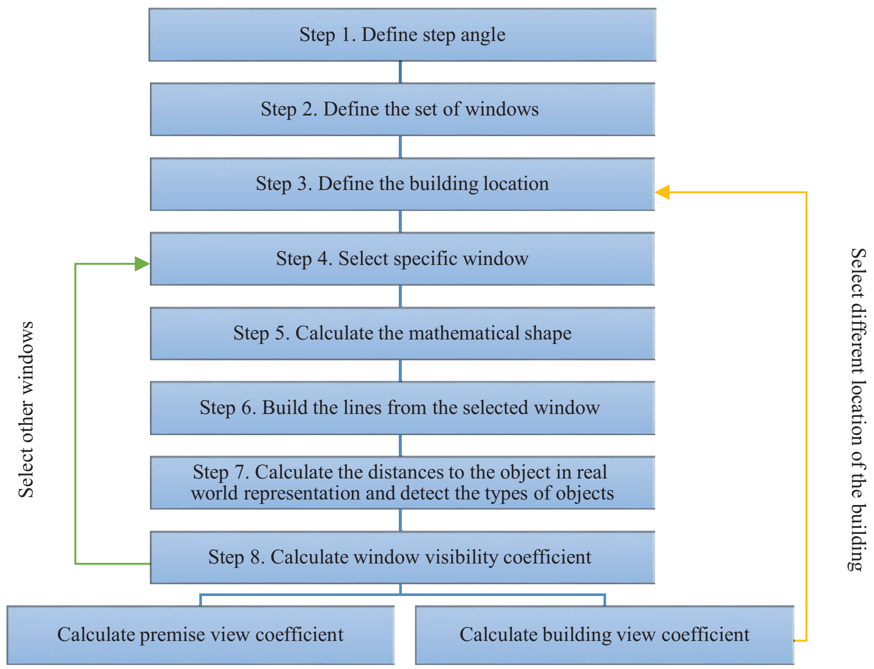


Figure 2. Methodological scheme of the window visibility analysis

analysis. For the analysis of alternative building locations, the set contains all the windows presented in the building. For property selling price prediction the set consists of windows in the exact premise.

In step 3, the location of the building should be specified. The building location is required once for property price prediction, but for comparison of alternative building locations, this step is repeated for different building locations, as is depicted with the yellow arrow.

In step 4, a specific window from the set of windows is selected for the analysis.

Step 5 contains the calculation of the mathematical shape, which involves the positioning of the sphere in the centre of the selected window and the calculation of the points on the surface of the sphere.

In step 6, the lines from the centre of the analysed window to the points on the surface of the mathematical shape are built using the step angle defined in step 1.

In step 7, the distances to the objects in real-world representation and the types of objects need to be determined. For this purpose the intersections of the built lines with objects in the real-world representation are determined and the length of the lines between the starting point and intersection point is calculated. After the length is calculated, it needs to be normalized to obtain the value in the range from 0 to 1. Based on the intersection point, the type of object is detected by using GIS map layers.

In step 8, the window view coefficient is calculated based on the normalized distances.

After the view coefficient is calculated for the specific window, the algorithm is repeated for the next defined window. The steps from step 4 up to step 8 describe the algorithm for the single window view coefficient calculation, therefore these steps are going to be repeated for each window defined in the set of windows specified in step 2 as is depicted by the green arrow.

After view coefficients are calculated for all windows that were specified, the analysis is split into two parts: property selling price prediction and comparison of the alternative building locations. In the case of property selling price prediction, the premise view coefficient is required to be calculated, and based on it the assessment of property selling price is performed.

To determine the rational location of a building, it is necessary to compare alternative locations of the building. In this case, the premise view coefficient is not required, but the building view coefficient needs to be calculated. After the building view coefficient is calculated, the alternative location of the building needs to be specified as is presented in step 3. When the location is defined, the analysis starts again for all windows. After the building view coefficient is calculated for each required location, the alternatives can be compared based on the building view coefficients. The resulting values depict the difference in views for all specified locations.

Based on the literature review presented in section 1 of this article, one of the key parameters that experts are looking for when analysing a view through windows is the real exact distance to the objects. For example, the distance to the forest or river, the distance to the nearby buildings or the absence of any objects that make obstacles looking through the window may affect the assessment. To calculate the distance between the point of observation and points on the mathematical shape of the view, the line-of-sight analysis is applied (Yu et al., 2007). The distance parameter can be presented as a line where the starting point is placed on the window position that is taken from the BIM model representation, and the ending point is placed on the place where the observed object is located. Based on the position of these points the distance parameter can be calculated. Figure 3 represents the code for a tool that allows building the line from starting point and casts the vector in a specific direction. This tool is used for all types of analyses presented in the experimental research.

```
let line = new Vector(0,0,0);
let direction = new Vector(0,0,0);
direction.subVectors(fromPoint, toPoint)
line.far = direction.length();
direction.normalize();
line.set(fromPoint, direction);
intersects = line.intersectObjects(3DMeshModel);
if (intersects.length>0) {return (intersects[0])}
return true;
```

Figure 3. Code for line tool used for the windows visibility analysis

This tool allows detecting the intersection point of the line with a 3D mesh model and calculates the distance attributes between the starting and the intersection points of the resulting line. In case no intersections were detected, the tool will return true (or 1). This parameter is used in further calculations.

Based on the intersection point the information about the object with which the intersection was detected can be defined. To determine the type of the object the GIS database such as OpenStreetMap need to be used by utilizing the application programming interface (API) Overpass (OpenStreetMap, 2021b) with parameters way, geometry and relation. This API provides information about grass, parks, playgrounds and forests, rivers, ways and roads, parking and buildings, etc. (OpenStreetMap, 2021c). However, not always the GIS databases contain information about all objects that are presented on the map, and the provided information is not always accurate. Nevertheless, this problem can be solved by connecting the GIS layers with the accurate information compiled by professional organizations. The information about the type of object, with which the intersection was determined, is going to be used in further calculations.

For the developed methodology it is important to analyse the view that can be seen from the window in both directions (horizontal and vertical), therefore, viewing angle is the second important parameter.

The view from the window has a maximum angle equal to 180 degrees in both vertical and horizontal directions (Carswell et al., 2010). Whereas there is no need to analyse the interior space of the premises, the sphere of interest for the mathematical representation of the view can be presented as a half-sphere directed outside the premise. If to imagine that some theoretical object takes 180 degrees of the view in a vertical direction, that means that the bottom of this object is located in negative infinity on the Z-axis, and the top of this object is somewhere in Z-axis infinity related to the observation point wherefrom the view angle is built. Every object existing in the view can be characterized by angles that will describe the part of the view where this object is located. Such angles can be built with two lines, where the first line is built from the observation point to the bottom of the object, and the second line is built to the top of the object as is presented in Figure 4. This method is used to describe the sphere of interest in both horizontal and vertical angles, therefore multiple lines need to be built with some step angle.

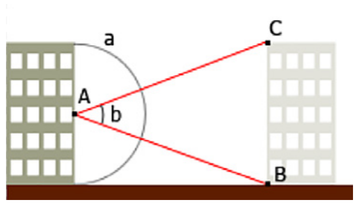


Figure 4. Vertical view angle, where: a – zone of interest that represents full view angle in 180 degrees; b – representation of the view angle for the object; AB and AC – baseline and topline of the object respectfully

Snellen (1862) and Sivtsev (1940) stated that the human eye can determine the two dots from the distance not smaller than 1 minute of arc (Correll, 1977). That means that at a 1000 m distance the observer's eye cannot see objects with a width less than 29 cm. This calculation can be done using angle chord calculation as is presented in Equation (1).

$$d = 2r \cdot \sin\left(\varphi \frac{\pi}{360}\right), \tag{1}$$

where: r – distance to the object and φ – step angle.

Such a statement allows concluding that there is no need to build the lines with the step angle smaller than 1 minute of arc. Moreover, the following calculation can be done: with the step of 1 minute of arc and with a maximum possible view angle of 180 degrees in both directions the total number of lines that need to be built is equal to 116661601 that can be calculated by Equation (2). This equation is used for checking the resulting number of lines and in the prediction of the analysis duration as it can require much time to be completed.

$$N = \left(\frac{\alpha_{max}}{\varphi} + 1\right) \cdot \left(\frac{\beta_{max}}{\varphi} + 1\right), \tag{2}$$

where: φ – angle steps; α_{max} and β_{max} are maximum horizontal and vertical view angles respectfully; N – the number of rays.

Time prediction is determined simply by calculating the difference between the starting time and current time considering the number of created lines (iterations) and the number of required lines. The function for time prediction is presented in Equation (3).

$$t = f\left(\frac{t_{now} \cdot N}{n} + t_{start} - t_{now}\right), \tag{3}$$

where: N – total number of lines calculated by Equation (2); n – current line (iteration); t_{now} – current time; t_{start} – time when the analysis started.

The process of lines' creation using the QUVIAS method in window visibility analysis is shown in Figure 5. The green lines are the lines that reached the sphere of interest and the values obtained are equal to its radius; the blue line represents part of the line that goes from the window to the intersection point with other objects and the value obtained is equal to the distance between those two points; the red line is the part of the line that represents the invisible part of the view; the white lines are lines that are excluded from the calculation as indoor measurements since window view analysis does not require information about indoor visibility.

The calculation performed by using Equation (2) shows that a large number of iterations is required to achieve maximum accuracy. The processing speed of computers is high nowadays, however, each iteration requires some time to be done. Such a problem is related to the web browser's limitations and WebGL environment limits. Therefore, a comparative analysis of different step angles was carried out. Such analysis allows determining the optimal step angle with the best ratio of accuracy and duration of the analysis. For the comparative analysis, an environment with ideal conditions was developed that includes a BIM model, a flat Earth surface and no extra objects. The results of this analysis are presented in Table 2. Additionally, this comparison allows determining the difference between the QUVIAS and existing methods for visibility analysis.

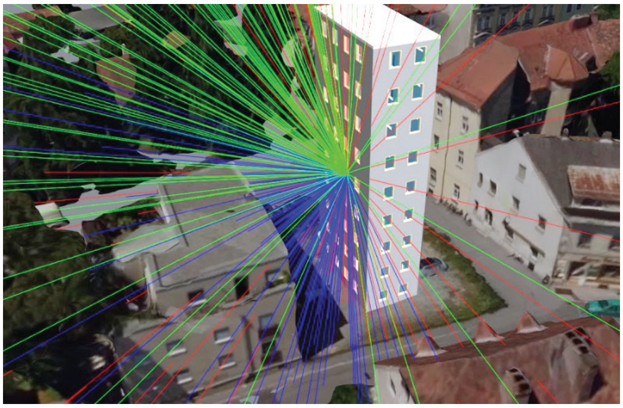


Figure 5. Performing window visibility analysis using the QUVIAS method

The "angle step" column shows the angle between the lines that connect the observation point and the points on the object being observed. A column "results of the analysis" presents the normalised results of the analysis. Column "required duration" depicts the time spent to perform analysis with each step angle. This value can be calculated using Equation (3). It should be highlighted that the duration of the measurements strongly depends on the processing speed of the computer where the analysis is carried out. Column "percentage (line interruption)" was calculated based on the sum of Boolean variables of the line interruptions divided by the total number of iterations. This column represents the results of the analysis that can be calculated by the existing methods for visibility analysis and represents the percentage (area) of the view clear from obstacles. Column "total iterations" presents the number of lines that were built to perform analysis.

The analysis reveals, that the results of the QUVIAS method presented in the "result of the analysis" column and values in the "percentage" column which are presented in Table 2 have a strong correlation, however, if convert the QUVIAS calculations into a percentage by multiplying by 100, then the difference between the values will be equal to 0.28. Surprisingly, even performing analysis in the ideal conditions with a flat Earth surface and with no any obstacles, the difference between the results can be

Table 2. Comparative analysis of step angles from one window

Angle step	Result of the analysis	Required duration	Percentage (line interruption)	Total iterations
180°	0.00006	0 sec	0	4
90°	0.33337	0 sec	33.333333	9
45°	0.40031	0 sec	40.0	25
22° 30' 30.00"	0.44513	0 sec	44.444444	81
11° 15' 15.00"	0.45094	0 sec	44.98270	289
5° 37' 37.50"	0.43101	0 sec	42.97521	1089
2° 48' 48.75"	0.42659	01 sec	42.48521	4225
1° 24' 24.38"	0.42543	05 sec	42.34121	16641
0° 42' 42.19"	0.42285	19 sec	42.05514	66049
0° 33' 33.75"	0.42161	33.38 sec	41.92015	103041
0° 21' 21.09"	0.42159	01:13 min	41.90425	263169
0° 10' 10.55"	0.42163	04:44 min	41.88878	1050625
0° 05' 05.27"	0.42150	18:28 min	41.86401	4198401
0° 02' 02.64"	0.42157	1:13:14 hour	41.86986	16785409
0° 01' 01.32"	0.42158	4:51:06 hour	41.87237	67125249
0° 01'	0.42156	12:16:56 hour	41.87108	116661601

seen. Further analysis revealed, that in the condition of real-world representation provided as a 3D mesh model the difference between these values is bigger. For example, an analysis of the ninth-floor window in the condition of a real-world representation model presented as a 3D mesh model depicts that percentage of line interruptions is equal to 39.21525 and the result of the analysis multiplied by 100 is equal to 40.39943. Depending on the objects presented in the real-world representation the inequality is different, some of the tests shown a difference of more than 4 percent.

From this observation can be stated, that the visibility analysis is not able to represent an accurate calculation of the view in case the distance parameter of the intersection with objects in real-world representation is not included. Such a conclusion proves the statements presented in the results of the comparative analysis presented in Table 1.

This article aims to present an accurate approach, therefore angles from 180° down to 11° 15' 15.00" cannot be used due to the big difference in the angle of 1 minute of arc. From Table 2 can be seen that the calculation with the step of the angle in 1 minute of arc requires more than 12 hours for the analysis for one window that is not suitable for a real project, therefore the optimal step angle needs to be defined. To present an accurate result the required accuracy has been defined as follows: the property price estimated by the analysis with optimal step angle should not differ more than 1 Euro per 1 m^2 of the property comparable to the analysis calculated with a step angle of 1 minute of arc. Based on the case study, suitable parameters have been determined: the difference of the line interruptions should be less than 0.05% and the difference of the resulting value should be less than 0.00005. By the experimental research, the angle 0°33'33.75" has been determined that rely on specified requirements, suits the defined accuracy, and requires not much time for the analysis.

After performing the analysis from one window the resulting array is going to be built. The size of the array for the angle equal to 1 minute of arc has a size of 116661601 elements. However, each element in the resulting array depends on the line length, therefore the elements of the array should be normalized using Equation (4).

$$a_{ij} = \frac{D_p}{R_{max}}, \tag{4}$$

where: D_p – distance to the point of intersection; R_{max} – the length of the longest line with no intersections that is equal to the radius of the sphere of interests; a_{ij} – element of the array.

After normalization, the array elements are ranged between 0 and 1, where elements with value 1 represent the line that didn't get any intersections and reached the endpoint that lies on the surface of the sphere of interest. In case the line has an intersection at some point, the value of this intersection is in a range from 0 to 1.

At this step, the normalized array can be considered as a mathematical representation of the view from the window. The presented approach is based on the angles and distances, which means that for each window used for analysis, the distances to the objects presented in the real-world representation model will be different. Therefore, the calculations do not rely on the height parameter. In other words, each window will have a different resulting array that is going to be shown in Section 4 of this article. To compare different windows, the window view coefficient needs to be calculated based on the normalized array using Equation (5). The same equation is used for the calculation of the object's types that are seen from the window, where j represents every single type of the object that was retrieved by the Overpass OpenStreetMap API. However, in the case of types calculation, the ranges from 0 to 1 are assigned for each type.

$$w = \frac{1}{n}\left(\sum_{i=1}^{n} a_{ij}\right), \tag{5}$$

where: i – identifier of the element; n – total number of elements in the array.

The obtained value is going to be used in the calculations of a property price prediction as a coefficient, therefore it can be named as a coefficient of the window visibility or simply window view coefficient. It allows to determine the influence of the view on the property price and can be used for automatic cost estimation or by the experts to help them to make their decisions. There are several ways how this coefficient can be used: for premises cost estimation and to assess the possible incomes of the newly built buildings.

For the premises price prediction, the premises view coefficient needs to be calculated. To calculate the premises view coefficient the window view coefficient of all windows presented in premises should be calculated. For this purpose, the premises' borders need to be found. This can be done by processing the attributive information of the objects that can be provided from the BIM model representation. In case the wall objects have enough parameters for automatic data gathering, then this action can be done without expert intrusion. However, most BIM models do not contain the information about rooms and apartments, therefore an expert would need to determine the required windows manually. After the required windows are selected the window visibility analysis should be carried out. The result of this analysis presents the set of the coefficients for all selected windows, which will be used to calculate the view coefficient for the premises using Equation (5). This coefficient allows describing the view of the exact premises quantitatively for different alternatives of the buildings or alternative building locations. For the expert calculations, the resulting values can be normalized in the same manner as presented in Equation (4). At the end of the analysis, all premises in the building will have the view coefficients.

Many methods (Pagourtzi et al., 2003; Bin et al., 2011) that include economically relevant characteristics for the price estimation exist, and multi-criteria decision-making analysis (MCDA) is usually used (Arribas et al., 2016; Helbich & Griffith, 2016). The aim of the presented method is not to indicate to experts how they should make their decisions, but to propose the way how the calculated coefficients can be used to get more accurate solutions. Therefore, the presented approach proposes to include the presented coefficients in the set of criteria to make accurate decisions.

Another possible use of the proposed method is for the analysis of the possible income of the project related to different alternative building locations. For this analysis, the view coefficient of the building must be calculated using Equation (5) based on the window view coefficient of all windows in the building. After the building view coefficient is calculated for one location, the same procedure must be performed for the alternative building locations. Finally, the achieved ratios can be compared with each other or used in multi-criteria analysis to determine the rational alternative.

3. Experimental research

The proposed approach was verified using the BIM model created with Autodesk Revit and placed into part of the city presented as a 3D mesh model. The experiment aims first to represent the window view by quantitative parameter and compare different views. Then, by using calculated window and premises view coefficients to estimate the influence and usefulness of these coefficients on property selling price. And finally, based on the view coefficient of the building compare two alternative locations of the building from the perspective of the attractiveness of the property.

3.1. Environment development

The integration of BIM, GIS and Web environments faces a big list of obstacles and challenges (Shkundalov & Vilutienė, 2021) which are interoperability issues, lack of standards and technics, the difference in semantics and scale of data, incompatibility of coordinate systems, the difference in applied procedures and other.

The lack of standards and technics (Shkundalov & Vilutienė, 2019a) is considered as one of the main obstacles to processing BIM models inside the Web environment. The main reason for this problem is the difference between semantic and geometry types where the BIM environment is using solid geometry within attributive information, however, GIS and Web environments mostly are based on B-Rep geometry within linked data. Therefore, BIM models need to be converted into Web supportable format for geometry visualisation and attributive information traversing. A variety of approaches and methods were proposed for solving these issues utilizing different file types, such as edited OBJ, IFC and JSON file formats, CityGML, WebAssembly, DEM, etc. Nevertheless, up-to-date no unified solution was presented and existing approaches cannot fully solve the issue of interoperability (Jusuf et al., 2017). For example, in IFC standard wall object is presented by the volumetric geometry component IfcWallStandardCase (buildingSMART, 2022) and in CityGML the BoundarySurface component WallSurface (Gröger et al., 2006) is used.

In the proposed method the BIM model may be presented in multiple ways, however since the proposed method aims to bring the automated solution for visibility analysis the usage of BIM models is important. The difference between the existing methods for presenting BIM models inside the Web environment is disputable, however, it needs to contain classes that would link the geometry of the objects with the relevant attributive information. Therefore, the usage of OBJ files, DEM and WebAssembly solutions is not sufficient. In the presented research two types of BIM model representation were used, which are the converted BIM model with embedded Revit families and the IFC model with IFC classes. Such BIM model representation allows gathering the information about all of the windows presented in the building as well as defining the borders of the premises in case the BIM model contains them.

Another issue that is related to the lack of standards and technics can be found in procedures and solutions (Shkundalov & Vilutienė, 2019b) that are presented in each environment. BIM, GIS and Web environments were developed for different purposes, therefore it is obvious that each of them involves its own set of procedures, solutions and methods for processing, storing and visualizing all kinds of data. According to such a situation, it is difficult to implement a solution that would meet the requirements of all three environments and would be suitable for processing the data in the same manner.

Another important issue is related to the difference in coordinate systems (Shkundalov & Vilutienė, 2020). Each environment i.e. BIM, GIS and Web, processes multiple coordinate systems, where local and geodetic coordinate systems are involved. The construction projects may involve both vertical and horizontal constructions and according to it, a different set of reference systems may be involved. On the other side, the Web environment is based on Web Mercator projection and requires coordinate transformation for processing coordinates presented in other coordinate systems. GIS environment is well known for utilizing a big list of coordinate systems, yet it does not involve the coordinate system of the BIM projects due to the proprietorship of BIM solutions.

This is a brief overview of obstacles and challenges that were faced in the research and developments presented in this article. Since this manuscript is not focusing on solving interoperability issues, the applied solutions are described shortly in the next section.

3.1.1. Real-world representation

To perform the analysis of the view that can be seen from the windows information about real-world surroundings should be gathered. For this research, the photogrammetry solution based on the automatic photo coupling that generates a 3D mesh model has been selected (Bentley, 2022). Nowadays this approach is widely used in GIS due to its high performance and low cost. To achieve the 3D mesh model with this method the photos of the area of interest should be captured. Usually, quadcopters or sailplanes with a high-resolution camera onboard are used. After photos have been captured they are processed by software solutions for 3D model generation.

As it has been stated in the literature analysis the types of objects that are in the view are important for the assessment of property selling price. However, the 3D mesh model contains information about the geometry of the objects, but it does not contain attributive information about the object. Therefore, by using only a 3D mesh model it is not possible to detect types of objects that can be seen from the window. Additionally, for the positioning of the objects inside the developed environment, the coordinate system must be implemented. Therefore, it is necessary to use GIS maps and databases. The geodetic coordinates presented by the GIS map are used for the positioning of the objects inside the developed environment, and information about objects in the real world can be obtained by using GIS databases. There are different map suppliers, including Bing Maps, Apple Maps, Yahoo Maps, and others, but Google Maps and OpenStreetMap are the most well-known from the perspective of the development. Google Maps and OpenStreetMap are the most well-known in the development process, therefore OpenStreetMap (OpenStreetMap, 2021a) was selected for this research.

3.1.2. Considering the environment

A wide range of different solutions can be used to process the 3D mesh model, such as professional 3D modelling software or BIM-specified programs, however, the solutions highlighted above do not have any kind of GIS analysis that is needed for window visibility analysis. On the other side, there is an opportunity to load a 3D mesh model inside the GIS software such as ArcGIS from ESRI (Esri ArcGIS, 2021) that provides the opportunity to process such models. However, GIS software does not allow to perform object detection based on BIM object specifications as well as does not have an interface to perform automatic calculations and comparisons. With this aim, another method should be designed. Such a solution has to provide the tools for 3D mesh model and BIM model processing and automatically perform calculations. For this purpose the Web environment has been chosen due to a wide range of tools that can process the 3D model and BIM model representations and due to multiple ways of development based on JavaScript (Shkundalov & Vilutienė, 2019a) and WebGL (Khronos Group, 2022) technologies. It should be mentioned, that the WebGL environment does not have a coordinate system by default. Therefore, there is a need to implement a coordinate system for further calculations. For this research, the three-dimensional Cartesian coordinates system has been used with the Z-axis as the Up axis.

3.1.3. BIM model representation

The integration of BIM allows performing the analysis at the early design stage of the construction project by gathering the information from the BIM model. By default, the Web environment does not provide the tools for BIM model processing and visualization because BIM models are usually stored in proprietary file formats, which cannot be processed outside the software where they have been created. On the other side, the BIM model can be converted into the Industry Foundation Classes (IFC) format that is used for BIM model sharing. However, the Web environment does not process IFC files either. One way how BIM models can be presented and processed inside the Web environment is to convert the BIM model into a Web supportable file format. There are two ways to convert the BIM model: server-side converters and software converters. Server-side-based converters such as BIMServer (Open Source BIM, 2022) and Apstex IFC Framework (Apstex, 2022) are based on Python or Java runtime environments that should be configured additionally, therefore for this article, the software-based solutions for Autodesk Revit have been chosen.

The developed environment with implemented 3D mesh model, GIS map, and BIM model representation is presented in Figure 6.

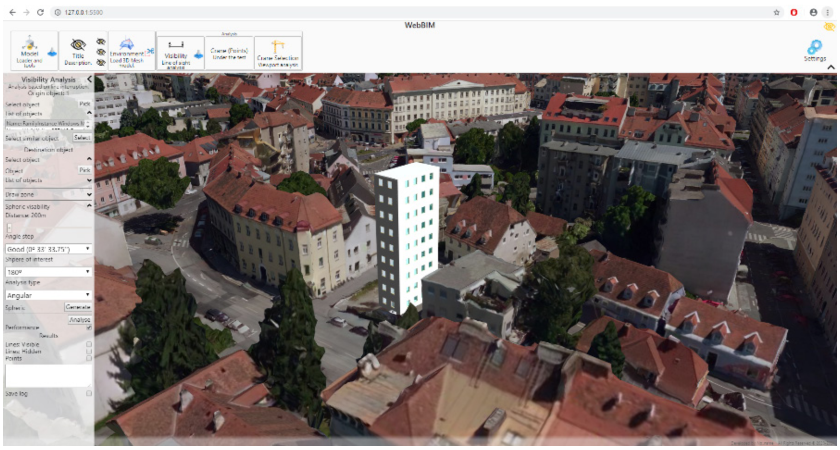


Figure 6. Implementation of the BIM model, GIS map, and real environment 3D mesh model inside the Web environment

The described functionality is implemented as a Web-based platform. Apart from mentioned above functions, the platform includes the core functionality, based on which the controls for the analysis are integrated (which can be seen on the left side of Figure 6. This part of the user interface is going to be used to carry all necessary inputs and tools for analysis, such as step angle, type of the analysis, the radius of the mathematical shape of the view, points, lines, window selection tool, etc. It should be highlighted, that developed analysis is a standalone solution that can be connected to any other web-based platform or implemented with another programming language.

3.2. Application of QUVIAS method in window visibility analysis

The first usage of the proposed QUVIAS method in window visibility analysis is to describe the view that can be seen from the windows as a quantitative parameter. For this purpose, two windows have been selected: the first window located on the second floor of the building and the second window on the ninth floor. The view that can be seen from the windows is presented in Figure 7.

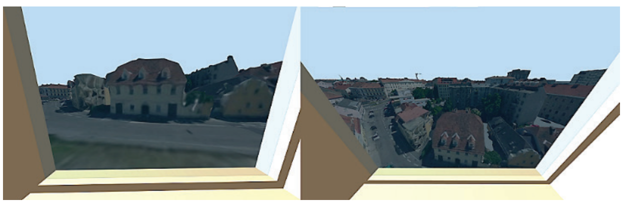
As it can be seen from Figure 7, the ninth-floor window has a much wider view as it is above the roofs comparable to the view from the second-floor window. The visualization of the results of the window visibility analysis performed employing the QUVIAS method is presented in Figure 8.

The window visibility analysis performed using the QUVIAS method described in Section 2 of this article shows that the view coefficient of the second-floor window is equal to 0.24730 and the view coefficient of the ninth-floor window is equal to 0.40399. The view of the second-floor window is 1.65 times worse compared to the ninth-floor window view.

Additionally, the analysis shows that based on the intersection points the view that can be seen from the second-floor window consists of 0.11266 (or 45.6% of the view) roads, 0.03710 (or 15%) buildings and 0.01030 (or 4.2%) undefined objects that are not presented in the OpenStreetMap database. The view from the ninth-floor window consists of 0.06509 (or 16.1%) roads, 0.11671 (or 28.8%) buildings, 0.00180 (or 0.4%) green areas, and 0.02469 (or 6.1%) unknown objects that were not defined in the database. The authors believe, that such precise information can be highly valuable for the experts in the assessment of property attractiveness.

Finally, yet importantly, it is necessary to check the conclusion from Section 3 of this manuscript that states the significance of the difference between a square (transformed sphere) and spherical shapes for the calculation of the window view coefficient. For this purpose, the window from the second floor was used for the analysis. The view from the window is presented in Figure 7a.

The analysis based on the square shape of the view presented the following parameters: lines interruptions equal to 0.17843 and window view coefficient equal to 0.22320. The analysis based on the spherical shape of the view depicted the following parameters: line interruptions equal to 0.20459 and window view coefficient equal to 0.24730. The difference between line interruptions and window view coefficients is 12.78% and 9.74% respectively. Such a big difference between the obtained values allows approving the conclusion stated in Section 3 that there is a significant difference between spherical and square (transformed sphere) shapes used as a mathematical representation of the view.

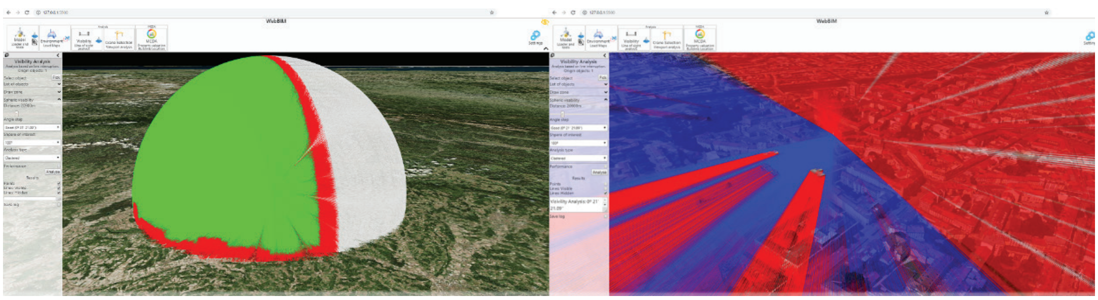


a) b)

Figure 7. Practical research of proposed window visibility analysis: a – the view from the second floor; b – the view from the ninth floor

3.3. The application of the proposed method in the prediction of project revenues

The proposed method can be applied by project developers for a more accurate prediction of project revenues. As was discussed in the literature analysis section, the window view parameter is considered as one of the criteria in the assessment of property selling price. In this section, the authors examine the effect that the coefficients determined by the proposed methods may have on the predicted price of a property.



a) b)

Figure 8. Visualisation of the QUVIAS method: a – view sphere presented by lines; b – part of the view sphere

By using the window view coefficients presented in the previous step the premise view coefficient can be calculated by using Equation (5). For this purpose, all windows in the premise need to be defined as it is highlighted in Section 3 of this article. Figure 9 presents the scheme of the flat boundaries presented in the BIM model. The same structure of the apartment is used for both the second and ninth floors.

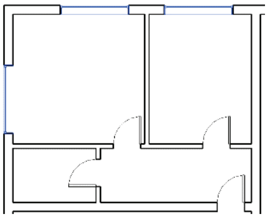


Figure 9. Required windows for the calculation of the premises view coefficient

As it can be seen in Figure 9 the premises contain 3 windows in their borders; therefore, for the calculation of the premises view coefficient the window view coefficient of all 3 windows must be calculated. Based on window view coefficients the premise view coefficient is calculated using Equation (5). For the premise on the second floor, the premises view coefficient is equal to 0.19816 and for the premises on the ninth floor, it is equal to 0.42199. A comparison of calculated coefficients differentiates the two views by 113 percent, where the view from the ninth-floor premise is twice more scenic compared to the second-floor apartment.

Furthermore, based on intersecting points and using Equation (5) for each type of objects, the view from the second-floor premise includes 0.06777 (or 34.2% of the view) roads, 0.04677 (or 23.6%) buildings, 0.03626 (or 18.3%) parking, 0.00040 (or 0.2%) green area, and 0.00357 (or 1.8%) undefined objects that are not included in the OpenStreetMap database. The view from the ninth-floor premise includes 0.04136 (or 9.8%) roads, 0.13461 (or 31.9%) buildings, 0.00380 (or 0.9%) green spaces, 0.00464 (or 1.1%) parking, and 0.03207 (or 7.6%) unknown items that were not identified in the database.

The selling price of the premise requires research that includes economically relevant characteristics for the price estimation. One of the criteria that influence the price of the premise is a view that can be seen from the windows. The view is a composite parameter that includes clearance of the view and types of objects that can be seen in view. As was discussed in Section 1 in most of the tasks for property price prediction and determination of the property attractiveness the view is considered as a qualitative parameter. The proposed premise view coefficients allow determining the view as a quantitative parameter for the premise that can be included in price prediction. Additionally, based on the comparison provided in Table 1 and Table 2, the results of the view calculation are more accurate compared to the GIS analyses which are used in view determination. Moreover, the QUVIAS method includes the determination of the types of objects that potentially can be highly useful in property price prediction. The clearance of the view presented by the premise view coefficient for the ninth-floor premise is twice higher compared to the second-floor premise. Such observation can be used by the experts in property price prediction methods, such as the comparable method (Colwell et al., 1983), hedonic price method (Rosen, 1974), and regression methods (Pagourtzi et al., 2003). Nonetheless, it should be emphasized, that estimation of the potential selling price is not the only usage of this method.

3.4. Comparison of alternative building locations

The view coefficients of the building calculated for different locations can be used to compare alternative locations of the building. For this purpose, the window visibility analysis should be carried out for all windows in the same way as they were calculated in Section 3.2 of this article. The selection of the windows can be done automatically by the attributive information collected from the BIM model or manually. The developed web-based platform provides a tool that allows determining the objects inside the BIM model representation by the use of the BIM classificator. The BIM model for this article was created by Autodesk Revit and contains 108 windows with the Revit classificator "Family Instances" (Autodesk Revit, 2022) equal to "windows". Therefore, it is possible to select all of them by the use of the classificator name. When all windows are selected for the analysis, the window view coefficient calculations can be performed for all of them. The resulting coefficients for the windows are presented in Figure 10.

As can be seen in Figure 10 the QUVIAS method in window visibility analysis allows determining the difference of the views even for the neighbouring windows. Based on windows view coefficients, the view coefficient of the building needs to be calculated by Equation (5), as all of the calculated coefficients can be presented as an array. For the first location of the building that is presented in Figure 6, the building view coefficient is equal to 0.29847. Since none of the existing visibility methods includes the distance in the calculation, both neighbouring windows

Figure 10. Windows view coefficients for all floors

will receive 0 in case the intersection appears and 1 if there is no intersection, but not a float number. Such observation allows proving that the QUVIAS method has an advantage compared to the other methods.

The analysis of the types of the objects calculated by Equation (5) based on intersection points shows that the average view from the windows in the case of specified location consists of 0.06865 (or 23% of the view) roads, 0.08283 (or 27.8%) buildings, 0.01448 (or 4.85%) parking lots, 0.00164 (or 0.55%) green area, and 0.01851 (or 6.2%) undefined objects that are not included in the OpenStreetMap database.

The same procedure must be performed for each desired building location to determine their difference. The second location of the building with the most suitable position and rotation is presented in Figure 11.

Based on the windows view coefficients, the building view coefficient for the second alternative of the building location has been calculated and is equal to 0.31904. The value of the building view coefficient for the second location of the building is 6.45% higher compared to the first building location (Figure 6).

The analysis of the types of the objects based on intersection points shows that the average view from the windows in the case of the second location consists of 0.02489 (or 7.8% of the view) roads, 0.06939 (or 21.75%) buildings, 0.05711 (or 17.9%) green areas, and 0.01659 (or 5.2%) undefined objects that are not included in the OpenStreetMap database. The view from the windows in the second location of the building contains a 46.9% larger view of the green area comparable to the first building location. Additionally, the percentage of roads in the view is much lower in the second alternative location.

Such comparison of the alternative building locations potentially can help in predicting the construction project revenue and can be useful in the MCDA tasks. It must be stated, that a defined difference in the values of the calculated coefficients does not mean that the difference in the results will be the same. The resulting value can be higher or lower depending on the weights the experts defined in the multi-criteria analysis. Nonetheless, the proposed view coefficient for alternative locations of the building can be considered an important parameter to look at in case all other parameters will remain the same for alternatives.

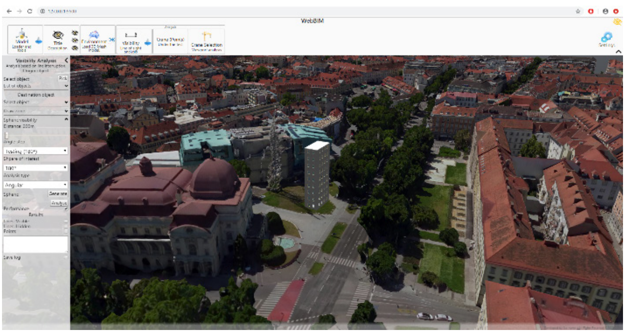


Figure 11. The second alternative of the building location

4. Discussions

The decision-making process in the early design stage of the construction project requires utilizing additional techniques to optimize the assessment of alternatives in uncertain conditions. The presented study employs BIM, GIS and Web environments to improve the decision-making in conditions when data about the construction object is insufficient.

The importance of the proposed QUVIAS method for visibility analysis arises since it allows analyzing the view that can be seen from the windows in uncertain conditions, such as early stage of a construction project when the construction is not yet built or construction solutions are not specified; or when the access to the object of analysis is not possible such as in pandemic situation, restricted areas, etc. The proposed method does not involve on-site measurements and is based fully on data gathered from BIM and GIS databases, which decrease time consumption, increase the accuracy by removing the human factor and allows the integration of the window view analysis into multi-criteria decision-making analysis.The presentation of the view as a qualitative parameter defined by linguistic grates is an approach that is used generally in the decision-making process. However, quantitative parameters are preferable since they do not involve subjective judgements. The proposed QUVIAS method allows to improve the window visibility analysis by calculating the view as a quantitative parameter.

According to the analysis of the research field, there are multiple methods for visibility analysis. Each method has its advantages and disadvantages. The line-of-sight method determines the distance to the objects in the most accurate way, however, does not allow analysing the full view, i.e. horizontally and vertically. The viewshed method was designed for analysing the view in both directions by defining relevant angles, however, it does not involve distance calculations as well as utilise the plane geometry as a mathematical shape of the view. The view dome method allows calculating the view in all directions considering the spherical nature of the view, however, does not involve the distance parameter in calculations. The QLA360 method is based on the spherical nature of the view as well as allows calculating the full view in both directions including part of the view, which is free from objects. However, the calculation of the view presented in this method is based on shape transformation, also this method does not involve the distance parameter.

A comparison of the proposed and existing methods for visibility analysis revealed, that utilisation of the sphere as a mathematical shape of the view and implementation of spherical coordinates increase the accuracy of the analysis. Such an approach ensures an even distance between the points on the surface of the mathematical shape and removes distortions of the transformation. According to Table 1, only QUVIAS and line-of-sight methods involve distance in calculations, from which solely QUVIAS can be used for calculating the view.

The proposed QUVIAS method calculates the view from the window and proposes three coefficients. The window view coefficient describes the view that can be seen from a single window. Applying this coefficient allows to differentiate the views from different windows and compare them. Based on the window view coefficient the premise view coefficient can be calculated. Premise view coefficient describes the view that is related to the single apartment. Based on this coefficient the view of different apartments can be compared. The building view coefficient proposed in this research describes the view related to the building. The utilisation of this coefficient allows to differentiate views in different locations of the building with different rotation angles.

The study revealed that it is rational to include the window view, premise view and building view coefficients calculated by the QUVIAS method in the decision-making process of the construction project because the integration of the proposed analysis allows the investor to assess the attractiveness of the project alternatives in a more precise way and gives the possibility to improve the decision-making process on the early stage of project development.

Since the view from the windows potentially can influence the selling price of the premise, more accurate analysis of the view can help in setting the potential selling price of the apartment by comparing the possible alternative solutions. Additionally, the proposed method may be useful for buyers and real estate agencies in determining the difference between available apartments with an additional parameter that describes the view.

The results of the study revealed that the inclusion of the building view coefficient allows the additional analysis of the building location alternatives, can improve the prediction of the property selling price in the planning stage of the construction project and can potentially influence the project revenues. The results confirmed the statement that view influences the property price (Baranzini & Schaerer, 2011) and proved the importance of applying BIM and GIS in civil engineering projects (Rafiee et al., 2014). The present study is in line with researches that concluded the importance of the distance parameter in the visibility analysis. The study showed that BIM and GIS have a much-unexplored capacity for solving complex technical issues in specialized areas of project development, and in particular, applications in the early conceptual design stage.

Conclusions

The proposed QUVIAS method has proven its efficiency by revealing a significant difference between the results obtained by the QUVIAS method and Boolean values that are used in existing methods. In existing practice, the view from the window is determined by linguistic grades as a qualitative parameter. Employment of the QUVIAS method allows to determine the view from the window as not qualitative, but a quantitative parameter that increases the accuracy of the decision-making process and allowed differentiate views.

The main novelty of the present study lies in its approach bringing together applications of BIM and GIS for the visibility analysis based on the spherical shape of the view, spherical coordinates and considering the distance parameter (as illustrated in Figure 1). Such an approach decreases projection distortions due to spherical coordinates, therefore highly increasing the accuracy of the view calculation. The experimental analysis depicted a significant difference (up to 9.74%) between spherical and square shapes used as a mathematical representation of the view.

Another contribution of the present study, demonstrates that, based on the experimental research and defined accuracy, the most suitable step angle for the window visibility analysis is 0°33’33 (as illustrated in Table 2). This part of the research allows decreasing the required time for the analysis without losing the accurate result.

According to the results of the case study the QUVIAS method allowed to differentiate views of two windows, where the second-floor window view coefficient is 1.65 times worse compared to the ninth-floor window. Such a precise comparison of the views allows concluding that the QUVIAS method is capable to analyse the view mathematically and present the view as a quantitative parameter, where even neighbouring windows have different window view coefficients (illustrated in Figure 10).

The proposed premise view coefficient calculated in the case study revealed a significant difference between the views of the analysed apartments and differentiate them by 113 percent. Such comparison potentially can be significant in the estimation of property attractiveness and selling price and may help in the decision-making process. Additionally, as was highlighted above, such representation of the view may be significant for real estate agencies and their customers for comparison of alternative apartments.

Another conclusion is related to the comparison of alternative building locations, where the proposed building view coefficient determined the difference between the views as 6.45%. Additionally, according to the determined types of objects the green area in the field of view at the second location is 46.9% larger compared to the first building location. Such comparison allows concluding, that the second location of the building is preferable compared to the first location since the potential selling price of the premises can be higher, which increases the project’s revenue in case all other location-related parameters of the building are the same.

Despite the contributions associated with the present study, all research studies have limitations, and the present study is no exception. First, it should be highlighted, that the proposed approach has performance limitations due to WebGL and web browser limits. Therefore further research can increase the performance that will allow using more precise step angles and decrease analysis time. Furthermore, the study, due to article size limitations, was focused on providing a methodology and validation, while no additional researches (such as GIS layers connection, comparison of alternative "random" type of point generation, description of the difference between step angles presented in Table 2, set of experimental analyses) that have been performed during development were described.

The implementation of BIM models inside the Web environment can be achieved by applying multiple methods and technologies. This task belongs to the integration and interoperability issues that were faced in the presented research. The difference between the existing methods is disputable since each method utilises different geometry types, procedures and data linking approaches. The comparative analysis of existing methods for integrating BIM models inside the Web environment would be sufficient research that would contribute to the research field. Therefore the authors consider such analysis as one of the vectors for further researches. The problems provided in this article were solved using two methods for BIM model implementation, which are the converted BIM model created by Revit software and IFC file type, and applying the method proposed by the authors (Shkundalov & Vilutienė, 2019a) for recalculation of the objects' coordinates presented inside the BIM model. Such an approach allowed to automatically determine the windows inside the BIM model and calculate their coordinates which allowed to automate the visibility analysis.

A comparison of different alternative building locations involves the inclusion of multiple criteria. If such an analysis is carried out at an early stage of the project, decisions have to be made with incomplete information. Models with exact values do not objectively describe possible options under such conditions. Multi-criteria decision models based on fuzzy logic is needed for solving problems in such conditions. The paper presents a new methodology and serves as a basis for future research. With the above in mind, in future work authors will expand the research by including the window view coefficients calculated by use of the proposed method in multi-criteria analysis of rational building locations.

Funding

This research received no external funding.

Author contributions

DS and TV conceived the study and were responsible for the design and development of the methodology. DS was responsible for data collection and analysis. DS and TV were responsible for data interpretation. DS wrote the first draft of the article. TV made supervision, review and editing. All authors have read and agreed to the final version of the manuscript.

Disclosure statement

The authors declare no conflict of interest and no any competing financial, professional, or personal interests from other parties.

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