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GIS-BASED SUITABILITY ANALYSIS FOR SKI RESORT DEVELOPMENT IN THE BRAN–RÂŞNOV AREA, BRAŞOV COUNTY, ROMANIA

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Abstract

This study assesses the suitability of an area located between the localities of Bran and Râşnov in Braşov County, Romania, for the development of a ski resort. A combination of cartographic resources - including orthophoto maps and topographic-cadastral plans - was initially employed, followed by detailed field measurements using GNSS technology. Climatic variables critical to ski infrastructure planning were evaluated using data from four meteorological stations, with a focus on air temperature, frost days, solid precipitation, and snow cover duration and depth. Geospatial analysis was conducted using GIS tools to examine key orographic parameters such as altitude, slope, aspect, shading, land curvature, and drainage patterns. By integrating climatic and terrain data, the study identifies the area as favorable for ski resort development based on both environmental suitability and technical feasibility.

***Key words**: ski resort, GIS, GNSS, terrain suitability, climatic assessment, spatial planning.*

INTRODUCTION

This study explores the potential for developing a ski resort in the northern and northwestern sector of the Bucegi Mountains, specifically in the area situated between the localities of Bran and Râşnov (Figure 1). The region is characterized by favorable topographic and climatic conditions and holds untapped potential for winter tourism infrastructure.

Despite Romania's mountainous geography, existing ski areas remain insufficiently developed. According to recent statistical evaluations, many resorts suffer from poor service quality and high operational costs, leading to a decline in domestic tourism in favor of more established destinations such as Austria. Additionally, numerous ski slopes in Romania have been developed at suboptimal altitudes or on poorly oriented terrain, resulting in limited seasonal usability and low investment returns (Comănescu et al., 2009). These issues are exacerbated by recent climate trends, including reduced winter precipitation and rising temperatures, particularly at lower elevations.

Considering these challenges, the identification of more suitable locations for ski infrastructure - both from a climatic and geomorphological perspective - is essential. This paper aims to evaluate such a location using integrated geospatial and climatic analyses.

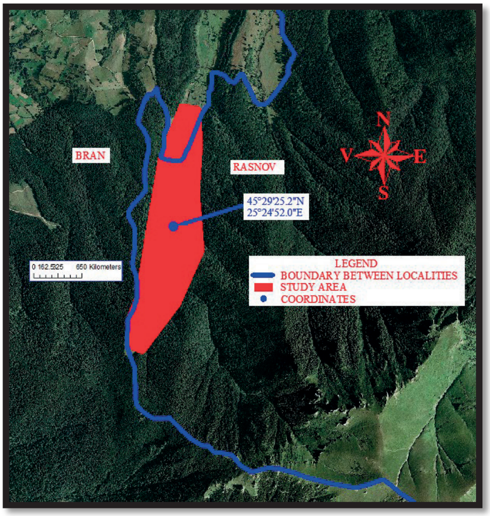

Figure 1. Study area

Both Bran and Râşnov have significant tourism potential, attracting a growing number of visitors during the winter season, including weekend travelers. Although there is an existing sports complex in the area that includes ski slopes, its usability is limited by two major factors: its low elevation and predominantly southern exposure. As a result, snow is either absent for much of the winter or melts rapidly after snowfall. Furthermore, recent years have seen a diversification of winter tourism activities beyond traditional skiing, increasing the demand for well-situated and versatile winter sports infrastructure.

The proposed ski resort would be located in a forested area, which is beneficial as forest cover positively influences snow retention and microclimatic stability (Nap et al., 2022). However, since the location lies within a protected area, all development plans must adhere to relevant environmental regulations and conservation principles (Olariu, 2019).

It is known that there are a number of constraints regarding the manner of removing an area from the forest fund, but this aspect was also thought beforehand and a suitable area was prepared (at the parity required by the Forest Code) to be introduced into the forest fund. The situation was studied on appropriate plans and maps (Teodor & Dobre, 2015), after which concrete measurements were made in the field. Steps were taken to obtain the appropriate permits.

Another important aspect to be taken into account in such investments is the possibility of snow avalanches (Jamieson & Johnson, 1998; Voiculescu & Popescu, 2011; Voiculescu & Ardelean, 2012).

The site is also favorable from a geomorphological perspective, with advantageous terrain curvature that minimizes excessive slope deformation during tight ski turns (Yoneyama et al., 2010).

To guide the development of the proposed ski area, several fundamental planning principles were applied (Cernaianu & Sobry, 2021):

Environmental integration: planning must ensure the preservation of natural resources - both ecological and visual - by aligning slope design with climate conditions, land use constraints, and natural hazard risks (Mihai et al., 2008, Wegler & Kuenzer, 2024). Understanding local environmental characteristics enhances the return on investment and promotes sustainable development (Ielenicz et al., 2010).

- *Customer-oriented planning:* this includes considerations of accessibility, market size and proximity, resort accessibility, and demographic and socioeconomic characteristics of the target clientele. Easy access is crucial for attracting tourists and investors alike (Lesenciuc et al., 2013). Estimating the proportions of day tourists versus overnight guests is essential for aligning slope capacity with lodging infrastructure. Lifestyle trends, age, income, and education level also influence demand (Gingulescu, 2010).
- *Operational and economic efficiency:* this involves optimizing slope capacity, estimating infrastructure and capital costs, human resource needs, revenue streams, and pricing strategies. These parameters are critical for assessing project feasibility and profitability (Ilieș, 2007).
- *Urban planning and legal compliance:* finally, all development must align with existing general urban plans (PUGs) and be supported by detailed zonal urban plans (PUZs) for both Bran and Râșnov (Ionescu, 2004).

MATERIALS AND METHODS

This study employed a combination of cartographic materials, remote sensing tools, GNSS-based field measurements, and geospatial analysis software to evaluate the suitability of the study area for ski resort development.

Materials

The following datasets and equipment were utilized:

- Orthophoto maps (2020 edition, scale 1:5,000; 2023 edition, scale 1:1,000);
- Topo-cadastral plans L-35-87-B-d-3-IV and L-35-87-D-b-1-II (scale 1:5,000);
- Forest management maps (scale 1:20,000);
- G7 South GNSS receiver with H6 data collectors, providing a horizontal accuracy of 25mm + 1 ppm RMS and a vertical accuracy of 15 mm + 1 ppm RMS;
- Dell Latitude 5411 laptop with Intel® Core™ i7-10850H CPU @ 2.70 GHz and 16 GB RAM;
- ArcMap GIS software;
- AutoCAD Civil 3D software;
- A topographic survey comprising over 4,500 georeferenced points.

Methods

The research methodology integrated the following techniques:

- *Direct geodetic measurements:* coordinates of key points within the study area were determined using GNSS equipment for high-precision spatial positioning.

- *GIS-based spatial analysis:* cadastral plans were georeferenced and vectorized. Custom analyses were conducted using VBA programming within the GIS environment to assess terrain parameters (e.g., slope, aspect, shading, curvature, drainage).

This multi-source approach enabled both the validation of field measurements and the derivation of relevant terrain and climatic indicators to support the site suitability assessment.

RESULTS AND DISCUSSIONS

Initial terrain analysis was conducted using topographic-cadastral plans L-35-87-B-d-3-IV and L-35-87-D-b-1-II, at a scale of 1:5,000. A preliminary evaluation of the study area revealed the following characteristics:

- An elevation difference of approximately 450 meters (the minimum altitude is 955m and the maximum is 1410m);
- Terrain gradients suitable for ski slopes across all skill levels, ranging from slopes of less than 20% (for beginners) to over 45% (for advanced skiers);
- A maximum slope length exceeding 3.2 kilometers.

Following the terrain assessment, climatic conditions relevant to snow retention and winter sports were analyzed. The study considered several key meteorological variables: average air temperature, number of frost days, monthly and seasonal solid precipitation, frequency of snow events, and snow cover duration and depth.

Climatic data were sourced from four meteorological stations in the region: Predeal (altitude 1096 m), Vf. Omu (altitude 2505 m), Sinaia 1500 (altitude 1510 m), Fundata (altitude 1376 m). Notably, two of these stations (Sinaia 1500 and Fundata) are located at altitudes similar to the target development site, providing a relevant climatic reference. The data spans the period 2014–2023, focusing on the core winter months: December through April. All data were collected from the National Meteorological Administration's network stations.

Table 1 presents the multiannual average air temperatures recorded during this period across the four stations.

Table 1. Multiannual average air temperature (°C) for the period 2014-2023

Station	December (XII)	January (I)	February (II)	March (III)	April (IV)
Predeal	-3.2	-4.3	-4.1	-0.2	4.8
Vf. Omu	-8.7	-10.5	-10.7	-8.2	-4.0
Sinaia-1500	-3.3	-4.8	-5.0	-1.5	3.3
Fundata	-3.2	-4.5	-4.5	-0.6	4.5

In terms of the number of frost days - defined as days with minimum temperatures below 0 °C - the observed data from the four meteorological stations over the 2014–2023 period is presented in Table 2.

Table 2. Average number of frost days per month (2014-2023)

Station	December (XII)	January (I)	February (II)	March (III)	April (IV)
Predeal	28.5	29.3	27.2	26.3	13.4
Vf. Omu	31.0	30.9	28.3	31.0	29.7
Sinaia-1500	26.6	29.3	26.8	25.7	13.6
Fundata	25.8	28.0	25.4	24.3	10.3

The next climatic factor considered in the analysis was precipitation, with a focus on parameters relevant to snow availability and sustainability in winter sports environments. The evaluation included the following aspects:

a. *Average monthly solid precipitation:* these values, presented in Table 3, reflect the total amount of monthly precipitation in solid form (e.g., snow, sleet). It is noted that the lowest values typically occur in February. However, this may be due to strong wind activity during that period, which can result in snow being redistributed or blown away, rather than reflecting actual precipitation scarcity.

b. *Average number of days with solid precipitation:* Table 4 summarizes the monthly averages of days featuring solid-phase precipitation, including snowfall, snow showers, sleet, soft drizzle, and fine snow.

c. *Snow cover characteristics:* observations are based on standardized 08:00 a.m. daily measurements recorded by meteorological stations across Romania. Two key parameters were analyzed:

- i. Average monthly snow depth, shown in Table 5;
- ii. Average annual duration of snow cover, presented in Table 6.

Table 3. Average monthly amounts of solid precipitation (mm), 2014-2023

Station	December (XII)	January (I)	February (II)	March (III)	April (IV)
Predeal	48.9	56.7	45.4	65.9	76.2
Vf. Omu	57.8	60.4	54.0	63.7	64.5
Sinaia-1500	73.0	62.7	62.2	58.2	73.5
Fundata	53.6	48.1	43.3	61.8	71.8

Table 4. Average monthly number of days with solid precipitation, 2014-2023

Station	December (XII)	January (I)	February (II)	March (III)	April (IV)
Predeal	11.4	12.3	12.9	12.1	3.6
Vf. Omu	13.0	12.9	13.5	16.6	16.2
Sinaia-1500	9.5	10.9	12.2	10.3	5.5
Fundata	11.0	12.7	13.9	12.7	5.5

Table 5. Average monthly snow depth (cm), 2014-2023

Station	December (XII)	January (I)	February (II)	March (III)	April (IV)
Predeal	18.8	30.7	44.1	33.0	4.6
Vf. Omu	43.1	63.9	83.8	101.0	104.0
Sinaia-1500	21.4	35.6	54.6	54.7	11.3
Fundata	12.3	22.5	32.8	28.6	2.5

Table 6. Average annual duration of snow cover (days), 2014-2023

Station	Average Duration (days)
Predeal	170
Vf. Omu	266
Sinaia-1500	178
Fundata	192

Following the climatic analysis, a detailed field survey was conducted to assess the orographic characteristics of the study area. The topographic-cadastral plans (L-35-87-B-d-3-IV and L-35-87-D-b-1-II) were georeferenced and overlaid on forest management maps obtained from the Bucegi - Piatra Craiului Private Forestry Office (Tereșneu, 2022). This process revealed that the proposed development area spans six forest management subcompartments.
Subsequently, an extensive field campaign was carried out, during which over 4,500 spatial data points were collected using a South G7 GNSS receiver and H6 controller. The coordinates of the boundaries for both the forest subcompartments and the proposed ski slope routes - classified by difficulty level - were precisely recorded. Due to the significant elevation differences and dense forest cover, the terrain presented logistical challenges during data acquisition. As a result, some of the initially mapped slope routes were adjusted based on field conditions.

To construct a detailed 3D topographic model of the area, the GNSS data were integrated with contour lines (with an equidistance of 5m) automatically vectorized using ArcScan (Tereșneu, 2013). In areas where GNSS measurements were not feasible, elevation data were extracted from the cadastral maps. To improve vertical accuracy, a custom algorithm was implemented to adjust the contour line altitudes. This correction accounted for historical modeling errors: 3D terrain models in forested areas were originally generated during 1960s-1970s photogrammetric surveys that captured canopy heights, necessitating corrections based on average stand height.
Studies by Tereșneu and Vasilescu (2019) have shown that stand height in mountainous terrain varies considerably - from taller growth at the base of slopes to shorter vegetation near ridgelines. These insights were incorporated into the correction model using data from forest management plans. Adjustments were applied through VBA-coded routines, ensuring that the contour lines accurately reflected ground elevation rather than canopy height.
Further analysis was conducted to evaluate the key orographic parameters relevant to ski slope planning. Each criterion was derived from a digital elevation model and associated spatial datasets, with results visualized in Figures 2 to 10.

- *Altitudinal analysis* (Figure 2). Due to recent climatic changes, ski slopes are recommended at higher elevations where snow cover persists for more than four months annually. In the study area, elevation ranges from a minimum of 955m m to a maximum of approximately 1400 m (1410 m), which is favorable for maintaining consistent snowpack during the winter season (5m resolution model).
- *Slope* (Figure 3 and 4). Slope gradient is a critical factor in ski slope classification. The terrain was analyzed and raster layers reclassified to generate a Boolean map of slope suitability. Areas with acceptable gradients were assigned a value of 1 (favorable), and steeper or flatter regions a value of 0. This analysis revealed that the area can accommodate slopes for all difficulty levels - from very easy to expert - based on the distribution of gradient classes.
- *Aspect (Exposure)* (Figure 5 and 6). Solar exposure significantly influences snow

quality and duration. Northern and northwestern exposures are preferred for preserving snow, especially at altitudes below 1500 m. The terrain was classified into seven 45° segments (sexagesimal) representing cardinal and intercardinal orientations. Southern-facing slopes (112.5°-247.5°) were excluded by assigning a value of 0, while others were assigned a value of 1. This exposure-based suitability analysis indicated that the majority of the area benefits from favorable orientations for slope development (Vorovencii, 2024).

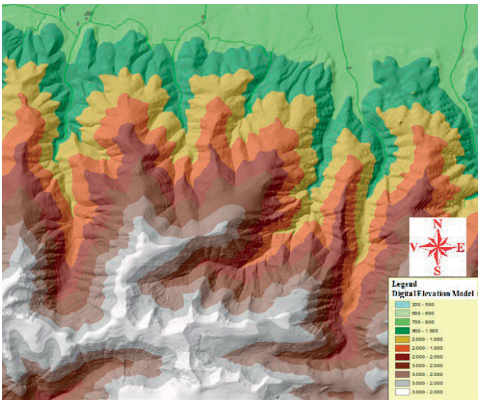

Figure 2. Digital Elevation Model (DEM)

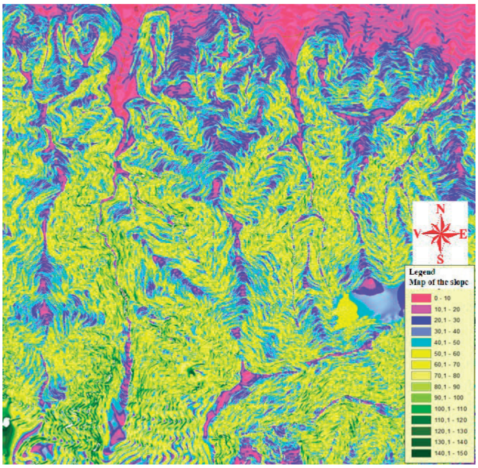

Figure 3. Slope Map of the Study Area

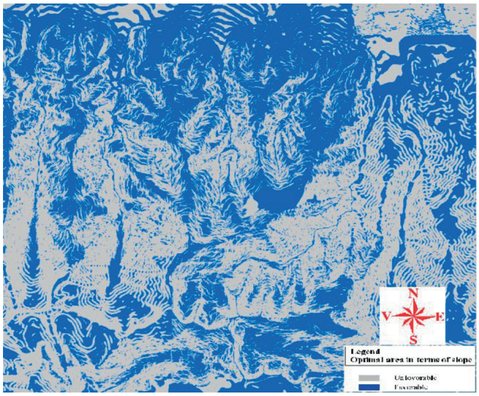

Figure 4. Slope-Based Suitability Map for ski area development

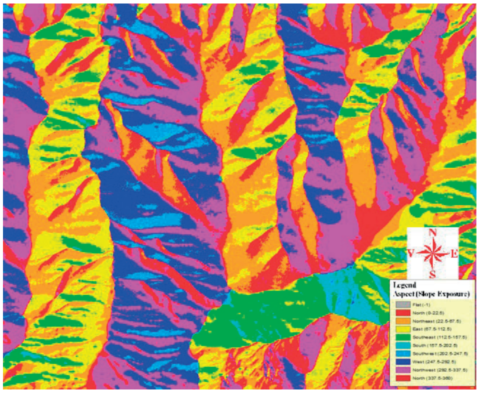

Figure 5. Aspect (Slope Exposure) Map of the Study Area

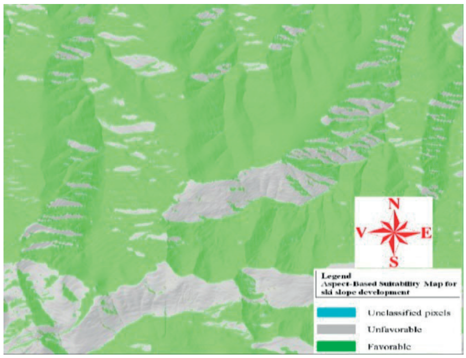

Figure 6. Aspect-Based Suitability Map for ski slope development

- *Shading* (Figures 7 and 8). Shading was analyzed using the Hillshade tool in ArcGIS, which simulates the illumination of the terrain based on specified azimuth and altitude of a hypothetical light source. This technique is not only useful for visual interpretation but also helps identify interpolation artifacts in the DEM. Shading maps were produced for two time points - 10:00 and 15:00 - on February 12 to assess variation in light exposure during typical winter conditions.
- *Land curvature* (Figure 9). Curvature is a morphometric variable that reflects surface convexity or concavity, influencing water runoff behavior and erosion susceptibility. The Curvature tool in ArcGIS was used to compute this parameter as the second derivative of the surface. In the resulting map, red indicates concave surfaces (potential accumulation zones), and yellow indicates convex areas (dispersal zones), which is useful for preliminary landscape stability assessments.
- *Flow Direction* (Figure 10). Hydrological flow paths were calculated using the Flow Direction tool from the Hydrology toolbox in ArcGIS. This analysis determines the direction of water runoff for each raster cell, based on the steepest descent among eight neighboring cells. While flow direction is not a primary determinant in ski slope planning, it is critical for identifying erosion-prone areas and designing sustainable drainage systems. The raster output supports broader environmental risk assessments during both construction and operation phases (Irimuș, 2006; Vorovencii, 2016).

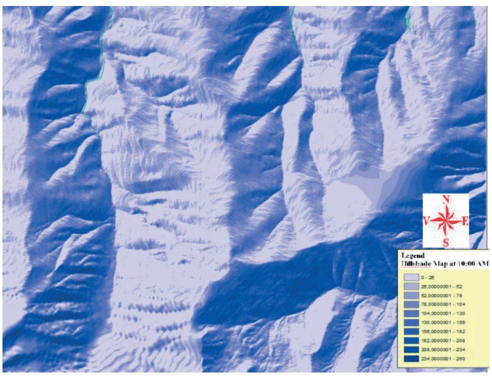

Figure 7. Hillshade Map at 10:00 AM on February 12

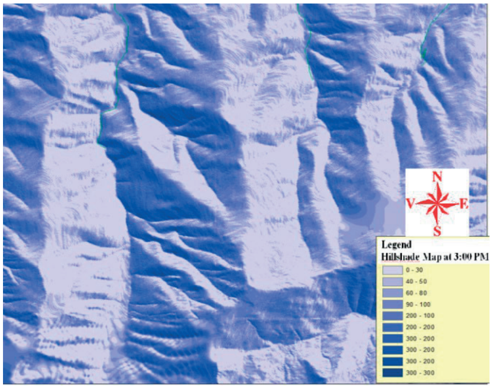

Figure 8. Hillshade Map at 3:00 PM on February 12

The result of the flow direction analysis is a raster in which each pixel's attribute value indicates the direction of surface runoff, calculated relative to its eight neighboring cells by identifying the path of steepest descent (i.e., the "shortest fall"). While flow direction does not directly influence the spatial placement of ski slopes, it is essential for assessing the potential for erosion. Such analyses are particularly relevant in mountainous environments, where natural erosion processes or slope destabilization can be intensified by infrastructure development and intensive slope usage. Understanding drainage patterns is therefore critical for mitigating geomorphological risks throughout both the construction and operational phases of a ski resort (Wang et al., 2024; Irimuș, 2006; Dietenberger et al., 2025; Vorovencii, 2016).

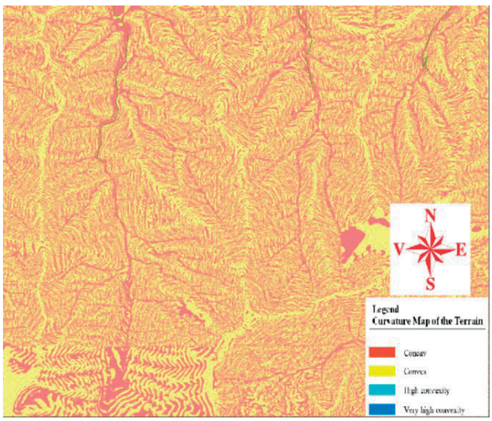

Figure 9. Curvature Map of the Terrain

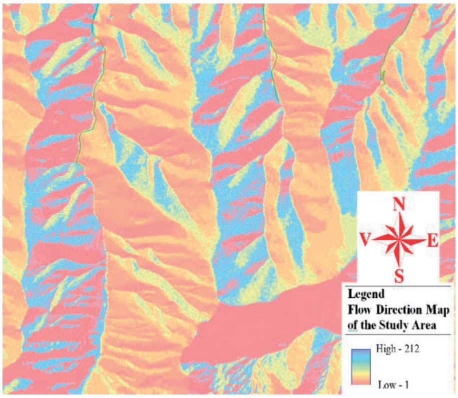

Figure 10. Flow Direction Map of the Study Area

CONCLUSIONS

Based on the integrated analysis of climatic conditions and orographic characteristics, the study area - located between Bran and Râșnov - is deemed suitable for the development of a ski resort. The conclusions are summarized below:

Climatic Factors

- Although recorded air temperatures have increased compared to previous decades (e.g., the 1970s and 1980s), they remain within acceptable ranges for maintaining snow cover, particularly when considered alongside other favorable climatic variables.
- The number of frost days supports the persistence of snow cover into April, extending the operational window of a ski slope.
- Average monthly snow cover, while not exceptionally high, is sufficient to ensure consistent slope usability during the winter season. Artificial snowmaking would be required only occasionally.
- Despite a downward trend, the frequency of days with solid precipitation remains adequate for natural snow accumulation.
- Snow cover characteristics - both in terms of thickness and annual duration - are favorable, confirming the natural viability of the site for winter sports.

Orographic Conditions

- Although the site's elevation (950-1400 m) falls below the ideal threshold of 1500 m, its overall suitability is reinforced through complementary terrain factors.
- The slope configuration accommodates all skier proficiency levels, from beginner to advanced.
- Aspect analysis indicates predominantly northern and northwestern exposures, which help offset limitations related to altitude by enhancing snow retention.
- Shading analysis places the area in a favorable category, particularly at higher elevations, reinforcing snow preservation potential.
- Terrain curvature suggests minimal need for significant grading or earthworks, which is beneficial for sustainable development.
- Flow direction analysis indicates stable drainage patterns and a low risk of landslides, confirming the geomorphological stability of the site.

In summary, the combined climatic and topographical assessment confirms that the studied area is highly suitable for ski resort development. Moreover, its location within an already well-developed tourist region with existing accommodation infrastructure further enhances its potential to attract a substantial number of winter sports visitors.

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