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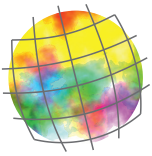

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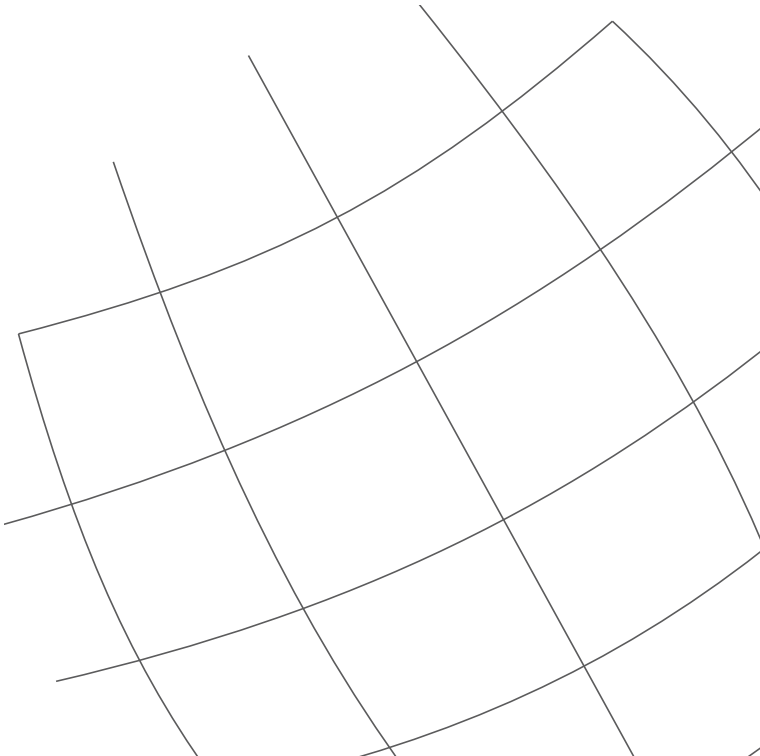

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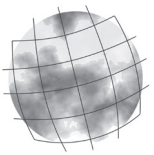

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CONTENT

EXPLORING DEMOGRAPHIC, SOCIO-ECONOMIC, AND ENVIRONMENTAL CORRELATES OF DIABETES DEATH RATES: A CASE STUDY OF CONNECTICUT, U.S.

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Abstract
Deaths caused by diabetes have increased significantly over the past 2 decades, becoming a public health concern in the U.S. Guided by social determinants of health theory, this research uses Ordinary Least Squares regression to examine the relationship between diabetes death rates and contextual demographic, socio-economic and environmental characteristics at the county subdivision level in the State of Connecticut, U.S. The results show that explanatory variables, such as percent of Hispanic population, population density, unemployment rate, the percent of population beyond 1 mile from supermarket, the percent of population beyond 1 mile for urban areas or 10 miles for rural areas from supermarket, the percent of households reported not having sufficient funds in the last 12 months to purchase food are statistically significantly associated with diabetes death rates. This research enables health practitioners and policy makers to gain a better understanding of the demographic, socio-economic and environmental determinants of diabetes death rates at the county subdivision level. Accordingly, provided are policies to reduce the death rates. This study presents an initial and exploratory step towards better understanding of diabetes death rates in Connecticut, U.S., but much more in-depth work is needed before health researchers and practitioners understand why explanatory factors only explained up to 57.8% of the diabetes death rates in the state.

Key words
Diabetes Death Risk, Regression, Connecticut.

INTRODUCTION

Diabetes is a chronic, metabolic disease characterized by elevated levels of blood glucose (or blood sugar), which leads over time to serious damage to the heart, blood vessels, eyes, kidneys and nerves. Diabetes constitutes a worldwide public health problem that affected 422 million people in 2014 (WHO, 2024a). In 2021, diabetes was the direct cause of 1.6 million deaths and 47% of all deaths due to

diabetes occurred before the age of 70 years (WHO, 2024b). Recent projections suggest that this prevalence is likely to increase in the next 20 years, affecting 592 million people (10.1%) in 2035 (Baena-Díez et al. 2016). In the U.S., 38 million people or about 1 in 10 Americans have diabetes (CDC, 2024a). Approximately, 96 million American adults or more than 1 in 3 aged 18 and above have prediabetes and more than 8 in 10 of prediabetes patients don't know they have it (CDC, 2024b). Diabetes and diabetes-related health complications can be serious and costly. As the eighth leading cause of death in the United States in 2021, diabetes costs a total estimated $413 billion in medical costs and lost work and wages (CDC, 2024c). In fact, people with diagnosed diabetes have more than twice the average medical costs that people without diabetes have. Additionally, diabetes is a major cause of blindness, kidney failure, heart attacks, coma, stroke and lower limb amputation and can consequently lead to deaths.

Diabetes prevalence is associated with demographic and socio-demographic variables, physical inactivity and built environment factors such as access to healthy foods and the rural–urban matrix (Hipp and Chalise, 2015). One of the great challenges in understanding the associations between built environment attributes and diabetes deaths is that both factors vary across Connecticut. Although studies of diabetes have found spatial variations in diabetes incidence and prevalence, there is a paucity of research on how the spatial prevalence of diabetes deaths may or may not be associated with the spatial prevalence of built environment attributes. Given this paucity, more empirical research is needed to investigate the spatial difference in diabetes deaths and identify contextual characteristics that underlie existing differences in diabetes deaths. In addition, the geographic studies of diabetes deaths were almost all carried out at the county level in the U.S., largely because this is the level that CDC compiles and disseminates diabetes death data. However, research conducted at the county level provides very limited implications for a state like Connecticut which has no county level government to implement policing, public health, and/or social policies.

OBJECTIVES

This research article fills these gaps by examining the relationship between the diabetes death rates and demographic, socio-economic, environmental predictors at the county subdivision level across Connecticut. It should be noted that county subdivisions are better known as cities, towns or municipalities in the U.S. This research benefits not only the academic community, but also the governmental agencies (i.e. public health or social services) that need to understand the geographical variations in demand for their services and the effective interventions that will have the best impact in reducing the deaths caused by diabetes. This is especially important in a post COVID-19 pandemic world where resources may be limited or depleted due to the high inflation.

LITERATURE REVIEW

Social determinants of health (SDOH) demonstrate non-medical factors can influence people's health outcomes and have emerged as a strategy for addressing health disparities (Hill-Briggs et al., 2020; Cooper et al., 2024). They are often quantified by the conditions in which people are born, grow, work, live, and age, and the wider set of forces shaping the conditions of people's daily life. Guided by SDOH as a framework and a salutogenic approach to health promotion, previous studies show diabetes death rates can be explained by a wide range of demographic, socio-economic and environmental variables. For example, age is a major risk factor for diabetes and prediabetes, since elderly people have a higher prevalence of diabetes and prediabetes than the younger people and are more likely to develop complications in the cardiovascular, retinal, and renal systems (Amir et al., 2020; Fong et al., 2021). Racial and ethnic minority populations have a higher prevalence of diabetes than non-minority individuals. Diabetes prevalence was higher among Black and Hispanic people compared to White people. The age- and sex-adjusted diabetes prevalence was 12.1% for non-Hispanic White, 20.4% for non-Hispanic Black, 22.1% for Hispanic (Cheng et al., 2019). Sex differences in body composition and fat deposition clearly contribute to the gap of diabetes risk between males and females (Mauvais- Jarvis et al., 2017; Ciarambino, 2022). Diabetes is more common in males rather than females. Worldwide, an estimated 17.7 million more men than women have diabetes (Kautzky-Willer et al., 2023). An empirical analysis of data taken from a Behavioral Risk Factor Surveillance System (BRFSS) conducted on rural and urban residents from 47 states in the US showed that a higher proportion of rural residents reported diabetes than urban residents among all racial/ethnic classifications (Hale et al., 2010).

Empirical research demonstrates that obesity is highly associated with perturbation of glucose metabolism, resulting in the development of type 2 diabetes (Chandrasekaran and Weiskirchen, 2024). Being overweight (Body Mass Index or BMI of 25-29.9), affected by obesity (BMI of 30-39.9) or morbid obesity (BMI of 40 or greater), greatly increases people's risk of developing type 2 diabetes, since the more excess weight a person has, the more resistant the person's muscle and tissue cells become to the person's own insulin hormone (Kahn and Flier, 2000). Mahoney et al. (2020) found that having health insurance was associated with decreased odds for undiagnosed prediabetes and type 2 diabetes in American adults. The findings highlight a large proportion of individuals without health insurance have undiagnosed prediabetes or type 2 diabetes and are therefore probably not managing their blood glucose levels properly (Mahoney et al., 2020).

Previous research discloses that mortality risk is higher among people with low socioeconomic status and diabetes as compared to those with higher SES and diabetes (Brown et al., 2004; Saydah et al., 2013). Varanka-Ruuska et al. (2018) found

unemployment was associated with 1.6-fold odds for prediabetes, and 1.7-fold odds for type 2 diabetes. Prevalence of diabetes disproportionately impacted lower-income populations. Compared with those with a middle income, the risk of development of type 2 diabetes for people with low income is 50% higher (Hsu et al., 2012). People with lower educational attainment tend to have poorer glycemic control and higher mortality risk (Doshi et al., 2016; Saydah et al., 2013).

Empirical studies shows that food insecurity is associated with increased all-cause mortality and compromised diet quality, especially in individuals experiencing very low food security (Fu et al., 2023). Food insecurity, for example, disrupted dietary patterns and food intake potentially leading to inadequate consumption of healthful food, is associated with adverse health outcomes including diabetes and cardiovascular disease (Ma et al., 2024). Poor access to healthy food has been linked to an increase in diabetes prevalence rate (Berkowitz et al., 2018). Food deserts exacerbate the limited access of healthy foods because of their lack of fresh produce and other healthy food options (Berkowitz et al., 2018). The death rate from diabetes in a food desert is twice that of areas with access to grocery stores (Curry, 2009).

The term polycrisis captures the complex nature of deaths caused by diabetes and their demographic, socio-economic, and environmental correlates (e.g. socio-economic inequalities, food insecurity, and healthcare disparities). Morin and Kern (1999, p. 74) proposed the term polycrisis over two decades ago. They emphasized that the most vital issue of nowadays was not any single threat but the 'complex inter-solidarity of problems, antagonisms, crises, uncontrollable processes, and the general crisis of the planet'. Lawrence et al. (2024) define a polycrisis as 'the causal entanglement of crises in multiple systems in ways that significantly degrade humanity's prospects. Matlovic and Matlovicová (2024) define polycrisis as 'the inter-connected crises in environmental, economic, political, social, health, and technological domains, whose combined effects are greater than the sum of individual crises'. Matlovic and Matlovicova (2024) also argue for adopting a post-disciplinary approach to study polycrisis.

STUDY AREA

Connecticut was one of the original 13 states and is one of the six New England states located in the northeastern corner of the USA. It ranks 48th among the 50 U.S. states in terms of total physical area but its population density ranks 4th. Connecticut has a mix of coastal cities and rural areas dotted with small towns. Totally, it has a mix of 169 county subdivisions, including 19 cities, one borough, and 149 incorporated towns. See Figure 1 below.

Lying in the midst of the great urban-industrial complex along the Atlantic coast, it borders Massachusetts to the north, Rhode Island to the east, Long Island

Sound (an arm of the Atlantic Ocean) to the south, and New York to the west. Hartford, in the north-central part of the state, is the capital. The state's greatest east-west length is about 180 km, and its maximum north-south extent is about 110 km. Connecticut is an important study area for contextual analysis of diabetes death rates due to the following reasons: 1) In 2017, diabetes was the seventh leading cause of death in Connecticut. Diabetes may lead to premature deaths. 2) There has been no scholarly research conducted in Connecticut on diabetes death patterns and their relationship to contextual characteristics of county subdivisions.

DATA AND METHODS

This study is based on drug overdose death data collected and managed by the Connecticut Department of Public Health (CDPH). The data consisted of 3,767 reported diabetes deaths that occurred in 169 county subdivisions in Connecticut from January 1st, 2018 to December 31st, 2022. Then, diabetes death rates were calculated for each county subdivision in Connecticut as the number of reported drug overdose deaths per 10,000 total population. See Figure 2 below.

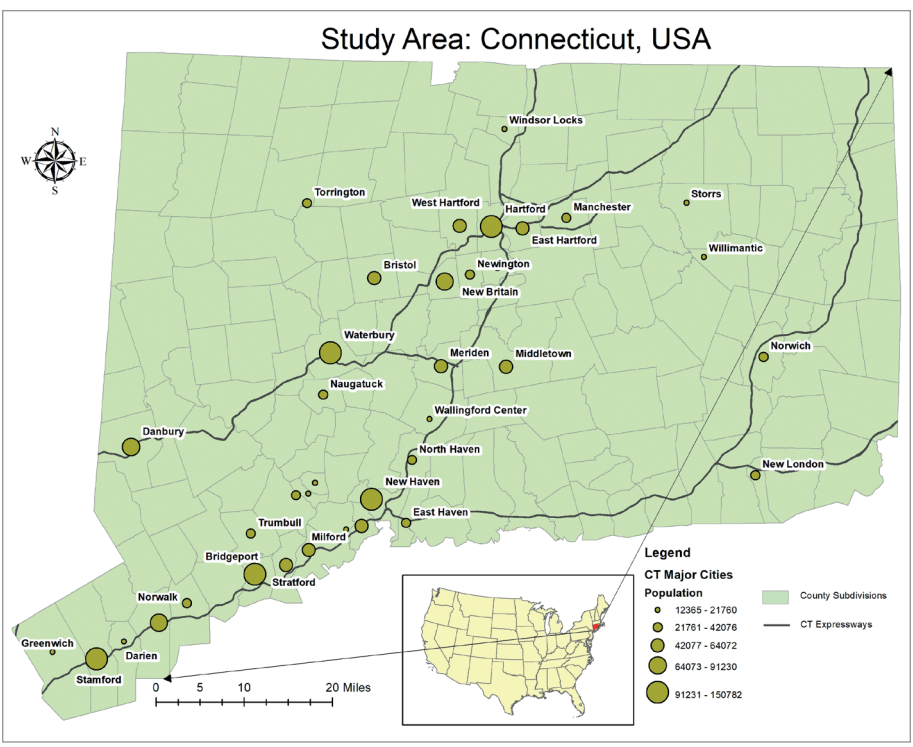

Fig. 1 Study Area: Connecticut, USA
Source: Census Bureau (2024; 2025)

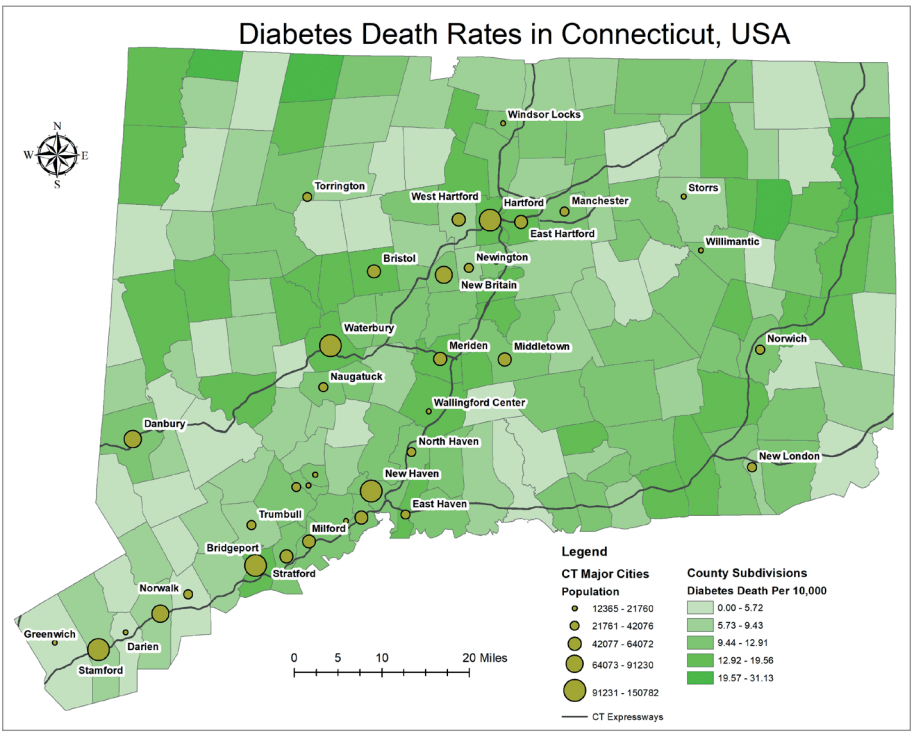

Fig. 2 Diabetes Death Rates in Connecticut, USA
Source: CENSUS BUREAU (2024; 2025); Connecticut Department of Public Health (2025)

The descriptive statistics for the dependent variable – diabetes death rates are shown in Table 1. Thereafter, the diabetes death rates table was joined with a shapefile consisting of 169 county subdivisions based on the unique 10-digit county subdivision Federal Information Processing System code assigned by the U.S. Census Bureau using ArcMap 10.8.2 (ESRI, 2021). This enabled the diabetes death rates to be later aligned with contextual variables for further analysis.

Tab. 1 Descriptive Statistics for the Dependent Variable – Drug Overdose Death Rates

	Min	Max	Median	Standard Deviation
Diabetes death rates: Diabetes deaths per 10,000 people	0.0	31.1	74.8	4.8

Source: Census Bureau (2024; 2025)

This study considers 16 contextual variables as potential explanatory variables and the descriptive statistics for each explanatory variable are shown in Table 2.

Tab. 2 Descriptive Statistics for the Explanatory Variables

Variables	Min	Max	Median	Standard Deviation
Demographic				
Age: % aged 65 and above	10.47	33.74	18.97	4.38
Race 1: % of Hispanic	0.38	46.11	7.12	8.68
Race 2: % of Blacks	0.00	54.75	1.98	7.21
Gender: % of males	39.91	62.17	49.64	2.79
Population density: the number of people per square kilometer	10.96	2950.96	169.74	472.24
Health				
Healthcare coverage: % without health insurance	0.60	14.30	3.10	2.50
Overweight and obesity rate: % of population whose BMI is equal or larger than 25	44.00	73.05	60.00	6.82
Disadvantage Status				
Joblessness: Unemployment rate	0.40	13.20	4.7	2.15
Poverty: % living under the poverty line	0.20	26.90	5.6	5.13
Education: % of people who don't have a college degree	12.62	79.03	48.37	14.18
Food Access				
% of population beyond 1 mile from supermarket	0.00	14.31	3.3	2.15
% of population beyond 1 mile for urban areas or 10 miles for rural areas from supermarket	0.00	91.07	25.79	27.28
% of households reported not having sufficient funds in the last 12 months to purchase food	2.00	33.30	8.00	5.06

Source: Census Bureau (2024; 2025); Connecticut Department of Public Health (2025)

The 11 contextual variables, covering demographic, health, disadvantage status, and food access were chosen to reflect the key dimensions underlying the variation in the risk of diabetes deaths as suggested by existing empirical research described in literature review. The demographic and socio-economic variables – residential population, age, race, gender, healthcare coverage, disability, joblessness, household type, education, and poverty were taken from the 2018-2022 American Community Survey (ACS) five-year estimates (Census Bureau, 2024).

The most recent overweight and obesity rate and the percentage of households reported not having sufficient funds in the last 12 months to purchase food were collected by DataHaven in 2015. The rest of the food access variables comes from Food Access Research Atlas which was prepared by the United States Department of Agriculture (2024).

The age variable was calculated by the percentage of people aged 65 and above. The race 1 and 2 variables were measured by the percentage of Hispanic and Black people in the residential population respectively. The gender variable was quantified by the percentage of males in the population. The population density was calculated by the number of people per square kilometer. The healthcare coverage variable was measured by the percentage of people without health insurance coverage. The overweight and obesity rate was quantified by the percentage of population whose BMI is equal or larger than 25. The jobless variable was determined by the unemployment rate. The poverty variable was measured as the percentage of people living under the poverty line. The education variable was calculated by the percentage of people without a college degree. The food access variable was quantified by the percentage of people living beyond 1 mile from the nearest supermarket, the percentage of people living beyond 1 mile for urban areas or 10 miles for rural areas from the nearest supermarket, and the percentage of households reported not having sufficient funds in the last 12 months to purchase food.

RESULTS AND DISCUSSION

The first step is to examine the dependent variable, diabetes death rates, and explore its spatial heterogeneity. If the dependent variable is not spatially clustered, there is no need to build a spatially explicit model. The Moran's I Index (Anselin, 1995) provided by ArcMap 10.8.2 (ESRI, 2021) was used to identify the clustering of diabetes death rates across county subdivisions in the State of Connecticut. Moran's I ranges from −1.0, perfectly dispersed (e.g., a checkerboard pattern), to a +1.0, perfectly clustered. In this research, Moran's I score (0.052) and p value (0.273) were generated, indicating that diabetes death rates in Connecticut are spatially random, and the results are statistically insignificant.

The OLS multivariate model (Aiken and West, 1991) in the Statistical Package for the Social Sciences (SPSS) 29 was then used to conduct linear regressions, since the dependent variable is not spatially clustered. If the standard regression equation in the investigation of the dependent variable is given by:

$$Y_i = \beta_0 + \sum_k \beta_k x_{ki} + \varepsilon_i$$

where Yi is the diabetes death rate at county subdivision i, β_0 is a constant term (i.e., the intercept), β_k measures the relationship between the independent variable x_k and Y for the set of i county subdivisions, and εi is the error associated with county subdivision i. It should be noted that i ∈ C = {1,2,…,n} which is the index set of locations of n observations (i.e. all county subdivisions in Connecticut). The summary of the OLS analysis results is presented in Table 3.

In the OLS regression, included were variables that are statistically significantly correlated with the diabetes death rates ($p < 0.05$). The OLS model is statistically significant ($F = 6.7$, $p < 0.01$). The R2 and adjusted R2 values are 0.623 and 0.578 which means that the OLS model explained 57.8% of the variance in county subdivision-level diabetes death rates in Connecticut. The VIF values for all variables was less than 5.0, a commonly used cutoff point (Becker et al., 2014; Ringle et al., 2015), suggesting no severe multicollinearity issue was detected among the explanatory variables (see Table 3). In other words, the correlations among the 5 included explanatory variables are low.

Tab. 3 Results from Ordinary Least Square Model of Drug Overdose Death Rates at County Subdivision-Level in Connecticut

Dependent Variable	Independent Variables	Standardized β	p value	VIF
Diabetes Death Rates	**Intercept**	-----	< 0.01	-----
	% of Hispanic	0.203	< 0.05	1.355
	The number of people per square kilometer	-0.221	< 0.05	1.732
	Unemployment rate	-0.161	< 0.05	1.342
	% of population beyond 1 mile from supermarket	0.273	< 0.01	1.554
	% of population beyond 1 mile for urban areas or 10 miles for rural areas from supermarket	0.151	< 0.01	1.153
	% of households reported not having sufficient funds in the last 12 months to purchase food	0.309	< 0.05	1.522

As shown in Table 3, there is a positive and significant relationship between diabetes death rates and the percentage of Hispanic people. In other words, the higher the percentage of Hispanic people in the population, the higher the diabetes death rates. The research result is consistent with previous research showing that Hispanics were 1.5 times more likely than non-Hispanic Whites to die from diabetes (Office of Minority Health, 2020). This conveys a huge cost or burden to Hispanic community in Connecticut. On one side, Hispanic population make

up the state's largest minority group, but they also have the highest poverty rate among the major race and ethnicity groups. According to 1-year estimates from the 2021 American Community Survey (ACS), there are roughly 637,113 people of Hispanic or Latino ethnicity residing in Connecticut, accounting for 17.7% of Connecticut's total population. Hispanic residents of Connecticut have a poverty rate of 21.4% in 2021 which is higher than the poverty rates of Asian (8.7%), White (17.3%), Black (17.3) and American Indians/Natives (20.7%). On the other side, the total estimated cost of diagnosed diabetes in Connecticut in 2017 is $3.7 billion. People with diabetes have medical expenses approximately 2.3 times higher than those who do not have diabetes. In addition, another $960 million was spent on indirect costs from lost productivity or lives due to diabetes. Since most of Hispanic population in Connecticut live in towns and cities located in Hartford, Fairfield, and New Haven counties, needed is a tailored diabetes intervention program for Hispanic population in those areas that promotes a healthy diet, regular physical exercises, maintaining a normal body weight, and avoiding tobacco uses. Diabetes can be treated, and its serious consequences can be avoided or at least delayed with a heathy diet, regular physical activity, affordable medication, and regular screening and treatment for complications.

There is a negative and significant relationship between diabetes death rates and the population density. In other words, the higher the number of people per square kilometer, the higher the diabetes death rates. The study result supports the previous research done by Dugani et al. (2022), showing U.S. rural areas have higher death rates caused by diabetes than more urbanized environments. Diabetes requires lifelong care. Accessing that care may be more difficult in rural areas than in more urbanized areas. In addition, people who live in rural areas may be at higher risk for developing diabetes at the first place. The Connecticut Office of Rural Health (CT-ORH) defines a Connecticut town as rural if it satisfies two conditions: the total population of the town is 10,000 residents or fewer and has a population density less than 500 people per square mile. There are 68 towns that meet the state's criteria for a rural designation. In addition, the CT-ORH definition includes towns that contain a census tract designated as rural by Health Resources and Services Administration as of 2020, adding 9 additional towns. This combined definition consists of 77 towns statewide which make up 45.5% of total number of county-subdivisions in Connecticut. In 2021, Connecticut has a population of 3,583,561 residents of whom 326,132 (9.1%) live in rural towns. Needed is improved access to diabetes preventive health services for the residents living in the 77 rural towns. The CT-ORH also needs to prioritize initiatives and dedicate resources to enhance access to quality and affordable health care for the rural Connecticut residents to avoid or delay diabetes related deaths.

There is a negative and significant relationship between diabetes death rates and the joblessness. In other words, the lower the unemployment rate, the higher

the diabetes death rate which is inconsistent with the literature (Varanka-Ruuska, et al. 2018; Wadhera et al., 2020). This may be caused by an increasingly serviced or sedentary lifestyle (i.e. watching TV; sitting at work and other sitting; increased mechanization and driving) in the employed population (Hu 2011; Richards et al., 2022). Additionally, a reduction in unemployment which often leads to an increase in average income would result in higher levels of spending on discretionary foods (i.e. high caloric with poor nutritional value), which may result in an increase in the prevalence of diabetes and consequently higher diabetes death rates (Penrose and Cava, 2021; Richards et al., 2022). Conversely an increase in unemployment may reduce the proportion of income spent on these discretionary foods (Penrose and Cava; Richards et al., 2022). According to Rodriguez-Sanchez and Cantarero-Prieto's (2017) research, diabetes prevalence is significant and negatively related to short-term unemployment (or unemployed for less than one year), but significant and positively associated with long-term (or unemployed for one year or more). People with diabetes are more likely to experience problems in obtaining employment after being unemployed than people without diabetes (Robinson et al., 1990). The ACS data do not differentiate the length of unemployment, so it is challenging to confirm whether the counter-intuitive relationship between the joblessness and diabetes death rates more likely applies to towns or cities that have higher short-term unemployment rates or not. More in-depth studies are needed to further investigate the relationship between joblessness and diabetes death rates in Connecticut.

There is a positive and significant relationship between diabetes death rates and the three food access variables. In other words, the higher the percentage of population beyond 1 mile from supermarket, the percentage of population beyond 1 mile for urban areas or 10 miles for rural areas from supermarket, the percentage of households reported not having sufficient funds in the last 12 months to purchase food, the higher the diabetes death rates. Research shows that adults who experience food insecurity are 2 to 3 times more likely to have type 2 diabetes (Fitzgerald et al, 2011; Seligman et al, 2007). Additionally, nutritious foods may be too expensive for some people, which limits healthy food choices. Foods that are cheaper and easier to find tend to be lower-quality processed foods. They're usually high in added sugars, saturated fat, and sodium (salt). While these foods can provide plenty of calories, they can increase the risk of developing type 2 diabetes. For people who already have diabetes, food insecurity can affect how well they manage their diabetes. Food insecurity can lead to diabetes-related complications, poorer mental health, hospitalizations and death. According to recent data from Feeding America, food insecurity is rising in Connecticut, disproportionately affecting Black and Hispanic households. Alarmingly, about 468,150 (approximately 1 in 8) Connecticut residents struggle with hunger and more than 112,000 (1 in 6) children are food insecure (Dewey

et al., 2024). Additionally, food deserts refer to areas where at least a third of the population (or 500 people) live at least one mile (if in a city) or 10 miles (if in a rural area) from the nearest grocery store. In 2019, the most recent data available, about 8 percent of Connecticut's census tracts were considered a food desert. Census tracts which are classified as food deserts are mapped on food access research atlas (U.S. Department of Agriculture, 2024). Living in a food desert exacerbates Connecticut residents' ability to access the healthy and fresh foods they want. As a result, it can lead to an increased risk of diabetes prevalence and increased mortality rates for the residents. Lifting communities out of poverty is a long-term solution to food insecurity, removing or alleviating barriers for food access could be a short-term solution. Needed are solutions such as providing tax incentives to encourage grocery stores opening in census tracts that are classified as food deserts by the U.S. Department of Agriculture (2024), regulating grocery stores to sell more unprocessed, fresh, and healthful foods; or expanding food assistance programs to low-income households in Connecticut.

The rest of the explanatory variables are insignificantly related to the dependent variable in this study. The residuals of the OLS model were not spatially auto-correlated (Moran's I = 0.044, p = 0.473), indicating that the OLS model neither overestimates diabetes death rates for some county subdivisions, nor underestimates the results for some others. Kolmogorov-Smirnov and Shapiro-Wilk tests were used to test the normality of OLS model residuals. Both p values are greater than 0.05 which confirms that the underlying residuals are normally distributed, meaning the OLS model's inferences (like confidence intervals and p-values) are reliable and less affected by outliers.

Tab. 4 Tests of Normality for OLS Model Residuals

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	**df**	**Significance**	**Statistic**	**df**	**Significance**
Standardized Residual	0.286	169	0.220	0.865	169	0.541

This study is not without limitations. First, county subdivision boundaries in Connecticut were used, so the relationships between diabetes death rates and contextual characteristics at the county subdivision level cannot be interpreted as and/or applied to individual level relationships. Second, it should be noted that the dataset prepared by the Connecticut Department of Public Health may underestimate the diabetes death rates to some extent, because the diabetes death data were compiled based on death certificates in Connecticut. However, the proportion of deaths attributable to diabetes in the US is as high as 12 percent—three times higher than estimates based on death certificates suggest (Stokes

and Preston, 2017). Third, diabetes death data were collected between 2018 and 2023, but the most recent food access variables were collected in 2019. The most recent and complete overweight and obesity rates in Connecticut were gathered in 2015. The temporal mismatch between the independent variables and diabetes death could affect the validity of the findings. In addition, the R2 values accounted for 57.8% of the diabetes death rates, which means that other risk factors (e.g. access to healthcare infrastructures, early diagnosis of diabetes, and a change of personal lifestyle) associated with the diabetes death rates need to be added into the OLS models. For example, dietary adjustments and exercise remain important components to reduce diabetes risks alongside the wide array of novel glucose-lowering medications (Yeh et al. 2023). Additionally, having regular check-ups and undergoing the required tests are important in the early diagnosis and treatment of diabetes. As a result of early diagnosis of diabetes, treatment can be started early and deaths caused by diabetes could be prevented or delayed.

CONCLUSIONS

The relationships between the diabetes death rates and contextual variables are still under investigation and little research has been done in Connecticut. This study discloses the complex nature of the relationship between deaths caused by diabetes and their demographic (i.e. percent of Hispanic and the number of people per square kilometer), socio-economic inequalities (i.e. unemployment rate), and environmental correlates (e.g. food insecurity and the percent of people living in the food desert) and calls for understanding it in the context of polycrisis framework (Lawrence et al., 2024; Matlovič and Matlovičov, 2024). By using OLS, health researchers and practitioners can gain an understanding of health-related issues and respond to the notion that "all health is local" (Gebreab and Diez-Roux, 2012). For example, the risk of diabetes mortality correlated strongly with unemployment rate, a measure of social stratification, increasing 2.5% for each 1% increase in unemployment rate (Wadhera et al., 2020). However, the death rate is largely negatively correlated with unemployment rate across the cities and towns in Connecticut. In other words, the diabetes death rates are more likely to be higher in cities and towns where unemployment rates are lower. In addition, the results of this study can also be used by the CDPH to tailor unique diabetes prevention and intervention strategies to different targeted cities and towns in Connecticut. This study presents an initial and exploratory step towards better understanding of diabetes death rates in Connecticut, U.S., but much more in-depth work is needed before health researchers and practitioners understand why explanatory factors only explained up to 57.8% of the diabetes death rates in the state.

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THE METAMODERN SHIFT IN GEOGRAPHICAL THOUGHT: OSCILLATORY ONTOLOGY AND EPISTEMOLOGY, POST-DISCIPLINARY AND POST-PARADIGMATIC PERSPECTIVES

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Abstract
In the article, we address the issue of a metamodern shift in geographical thought, reflecting on the context of the current Anthropocene polycrisis, which encompasses a range of environmental, geopolitical, economic, and socio-cultural challenges of the present era. We start from the assumption that postmodern epistemological and methodological frameworks are insufficient for a comprehensive understanding and resolution of these challenges. In this context, we explore the potential of metamodernism as a new philosophical and scientific platform that oscillates between modernist rationalism and postmodern skepticism, allowing for the productive integration of these frameworks.
The primary objective of this study is to demonstrate how metamodernism can contribute to the reinterpretation of geographical thought and to identify its potential as the fifth first-order discontinuity in the historical development of this discipline. In the theoretical and methodological section, we discuss discontinuities in scientific thought and apply the Latour-Barnes model to analyze the phases of mobilization and autonomization of metamodernism within academic discourse. We introduce key metamodernist concepts and principles - metarealism, zetetism, hylosemiotics, sublation, oscillation of scientific discourses, the paradoxical position of truth and grand narratives, dia/polylogical thinking, and the coexistence of layers of cultural evolution (Pipere, Mārtinsone, 2023, Storm, 2021), — and outline their applicability in geographical research. We employ qualitative, discourse-based, and historical-contextual methods to examine the metamodern shift in geographical thought, focusing on epistemological, ontological, and methodological transformations.
We reinterpret geography as a post-disciplinary and post-paradigmatic scientific discipline that oscillates between various ontological, epistemological, and methodological frameworks. In this context, we emphasize the necessity for

an open, reflective, and pluralistic approach that facilitates the integration of diverse types of knowledge and methodological strategies. Understood through the lens of metamodernism, geography becomes a field of dynamic oscillation between the natural sciences, social sciences, humanities, and technological interpretations of reality. This conceptualization of geography addresses the need for comprehensive, practice-oriented knowledge that can tackle contemporary global challenges, such as polycrisis. This aligns with zetetic epistemology, which prioritizes abductive reasoning (inference to the best explanation) over rigid deductive or inductive models. We introduce hylosemiotics as a methodological tool that enables researchers to analyze material-symbolic interactions in space and place. This approach integrates semiotic analysis with material studies, providing a novel framework for interpreting geographical landscapes.
In doing so, we aim to encourage discussions about applying metamodernist concepts in geographical thought while also acknowledging its limitations and potential risks. Moreover, we underscore the necessity for further theoretical and empirical reflection to refine methodological strategies and practical applications of the metamodernist framework in geographical research.

Keywords
Geography, geographical thought, hylosemiotics, metamodernism, metamodern shift, metaxy, oscillation, polycrisis, post-postmodernism, zetetic epistemology.

INTRODUCTION

The extraordinary dynamism of the contemporary era is reflected in the Anthropocene polycrisis (Matlovič, Matlovičová, 2024), which encompasses the environmental impacts of climate change, the ongoing transformation of the global geopolitical order, the end of economic globalization (see, for example, Zeihan, 2022), the looming collapse of modern societies (Turchin, 2023), the decline of capitalism and the emergence of techno-feudalism (Varoufakis, 2024), the rise of artificial intelligence, and shifts in the perception and interpretation of reality within post-Enlightenment and post-truth contexts (Derakhshan, 2021). This situation presents a significant challenge to the scientific community, prompting questions about the adequacy of existing epistemologies and methodologies in interpreting the contemporary world and devising practical solutions for the sustainable development of human civilization (Matlovič, Matlovičová, 2024). Maxwell (2024) argues that academic inquiry has predominantly emphasized 'knowledge-inquiry' over 'wisdom-inquiry, which encompasses not only knowledge but also its application in solving real societal problems.

In this context, it is noteworthy that, over the past two decades, there has been an increasing number of arguments within culture and philosophy questioning the adequacy of postmodernism as an explanatory framework for understanding the essence and complexity of contemporary societal phenomena, cultural trends, and developments in art, philosophy, and science (e.g., Hughes, 1996; Hutcheon, 2002; Hassan, 2003; Kirby, 2006; Toth, 2010; Rudrum, Stavris, 2015; Clare, 2017). There has been growing reflection on emerging cultural tendencies that succeed

postmodernism. These reflections emphasize the reinterpretation of historical events and narratives, thereby moving beyond postmodern skepticism towards grand narratives. A notable trend is the renewed emphasis on sincere emotions and authentic experiences in contemporary culture, contrasting with postmodern cynicism and irony. There is also a renewed interest in depth and meaning in artistic and cultural expressions, differing from postmodernism's focus on superficiality and simulacra (van den Akker, Gibbons, Vermeulen, 2017).

In this regard, various conceptualizations of new movements aiming to replace postmodernism have emerged. The first anthology of key texts (Rudrum, Stavris, 2015) discusses multiple concepts, including altermodernism (Bourriaud, 2009), automodernism (Samuels, 2007), hypermodernism (Lipovetsky, 2005), metamodernism (Vermeulen, van den Akker 2010), performatism (Eshelman, 2008), post-postmodernism (Nealon, 2012), pseudomodernism/digimodernism (Kirby, 2009), remodernism (Childish, Thomson, 2000), and renewalism (Brooks, Toth, 2007). Among these concepts, metamodernism has gained the most traction in philosophy and scientific inquiry (Pipere, Mārtinsone, 2022).

The aim of this paper is to explore the metamodern shift in geographical thought by examining its ontological, epistemological, and methodological implications, positioning it as the fifth first-order discontinuity in the development of geographical thought as understood in our previous work (Matlovič, Matlovičová, 2020). We briefly outline the development of metamodernism and its reception within philosophy and scientific inquiry. Subsequently, we introduce the key concepts and principles of metamodernism and indicate its potential for adoption within geographical thought. We seek to promote discussion regarding the application of metamodernist concepts in geographical thought, while simultaneously highlighting the limitations and risks of this approach. Moreover, we underscore the necessity for further theoretical and empirical reflection to refine methodological strategies and practical applications of the metamodernist framework in geographical research.

THEORETICAL AND METHODOLOGICAL FRAMEWORK, DATA, AND METHODS

The foundational theoretical basis of our considerations is rooted in the reception of the idea of discontinuity in scientific thought, which emerged as a response to the rejection of the linear-cumulative model of the history of science, as advocated by positivist historiography. We have previously discussed this idea in the context of the development of geographical thought (Matlovič, Matlovičová, 2020). In this regard, the work of Kuhn (1962/1970) is particularly relevant, as he defined discontinuity as a scientific revolution characterized by a paradigmatic shift, involving a fundamental transformation at the ontological, methodological, and

axiological levels of science. Kuhn's concept of paradigm shifts also introduced the problem of incommensurability, indicating that new paradigms are not always fully compatible with preceding ones (Kuhn 1970).

I. B. Cohen (1987) proposed a historical analysis of scientific revolutions through four universally applicable tests, acknowledging both the objective and subjective dimensions of discontinuity in science. Lakatos (1970) introduced the concept of scientific research programs, asserting that discontinuity occurs only when there is a change in the "hard core" of the program—a process he deemed rare. In contrast, Laudan (1984) criticized the notion of complete discontinuity in paradigmatic shifts and suggested a network model, where levels of science (ontological, methodological, axiological) are not hierarchically interconnected. Foucault (2000) introduced the concept of the episteme, emphasizing that discontinuities in knowledge are not causally inevitable but arise from power relations and historical contingencies. Retrospectively, M. Cohen (2015) described the concept of paradigmatic shift as an "intellectual virus" that had also permeated the social sciences, humanities, and even political discourse (Matlovič, Matlovičová, 2020).

Building upon this framework and following Peet's (1998) discussion on five levels of generalization, we identified two orders of discontinuities in geographical thought. First-order discontinuities represent fundamental changes at the level of worldview paradigms (metaphilosophical and philosophical levels, according to Peet, 1998). Second-order discontinuities pertain to changes at the level of disciplinary matrices (philosophical and socio-theoretical levels). Based on this hierarchical classification, we identified four first-order discontinuities and sixteen second-order discontinuities in the historical development of geographical thought (Matlovič, Matlovičová, 2020). Given that the most recent first-order discontinuity in geographical thought was the postmodern discontinuity, and considering that metamodernism aspires to succeed postmodernism, it is reasonable to consider the metamodern shift in geographical thought as the fifth first-order discontinuity in its history.

For analyzing the progression of the metamodern shift in scientific thought, we adopt the Latour-Barnes model of disciplinary change, originally applied to the analysis of the rise and decline of regional science (Barnes, 2004; Johnston, 2006, p. 286; Matlovič, Matlovičová, 2015, pp. 18–20; Matlovič, Matlovičová, 2021). This model is based on Latour's classification of phases through which a scientific discipline passes during its paradigmatic transformation (Latour, 1999). The successful progression through these phases is deemed essential for achieving transformative change.

The first phase is mobilization, initiated by a group or individual articulating a new agenda. The second phase, autonomization, involves systematic engagement with the academic community to stimulate acceptance, internalization, and

subsequent expansion of the new agenda within the discipline. The third phase, building alliances, is a dynamic process overlapping with the previous phase, aiming to establish the new agenda in a broader disciplinary context through institutionalization. The fourth phase, public representation, extends the previous phase by expanding the agenda's influence beyond academic structures into the wider societal context (Johnson, 2006; Matlovič, Matlovičová, 2015).

Ideally, the competition for advancing a new agenda within a scientific discipline should culminate in rational deliberation guided by the strength of arguments. However, in reality, the process is influenced by institutional rivalries and political strategies. In this context, six political strategies are employed. The first four—politics of denigration, criticism, rejection, and silence—are characteristic of the mobilization and autonomization phases. The latter two—politics of adaptation and politics of unification—prevail during the alliance-building and public representation phases, as the discipline seeks to maintain competitiveness within the broader academic and societal framework (see Johnston, 2006; Matlovič, Matlovičová, 2015).

We interpret the introduction of metamodernism into academic discourse as the mobilization phase in accordance with the Latour-Barnes model, while its reception within the philosophy of science and scientific thought represents an attempt at autonomization. Furthermore, we highlight the political strategies applied in advancing the metamodern shift.

This contribution employs an interdisciplinary approach, integrating multiple methodological strategies from the philosophy of science, epistemology, cultural theory, and geographical thought. The methodology is predominantly qualitative, analytical, and historical-contextual. The article is grounded in extensive content and discourse analysis of relevant sources, encompassing philosophical, cultural, and geographical theories.

The selection of literature for this study was guided by the following criteria to ensure comprehensiveness and relevance: relevance to metamodernism and geographical thought (sources were selected based on their direct engagement with key concepts of metamodernism, as well as their relevance to geographical thought and philosophy of science), and diversity of perspectives (to capture a plurality of viewpoints, literature from diverse philosophical, geographical, and cultural frameworks was incorporated). Special attention was paid to including both advocates and critics of metamodernism. We analyzed the selected literature using qualitative content and discourse methods, focusing on how metamodernist concepts are articulated. Key themes were identified and coded, such as the evolution of metamodernist thought, conceptual integration with geography, and methodological implications. Concepts were systematically compared with modernist and postmodernist frameworks to highlight points of convergence, divergence, and transformation within geographical thought. Throughout the

analysis, efforts were made to remain critically reflexive, recognizing potential biases arising from personal academic orientation and interpretative frameworks. The inclusion of diverse sources aimed to mitigate subjective influence. Particular care was taken to critically evaluate both supportive and critical perspectives on metamodernism, ensuring balanced representation. Interpretative conclusions were cross-referenced with primary source arguments, and areas of ambiguity were acknowledged. This approach sought to avoid overinterpretation or misrepresentation of philosophical positions.

THEORETICAL FOUNDATIONS OF METAMODERNISM IN CONTEMPORARY SCHOLARSHIP

The process of forming metamodernism as a new intellectual agenda can be analyzed within the context of the mobilization phase, as conceptualized in the Latour-Barnes model. Here, initiators articulate new theoretical foundations, challenging the paradigmatic framework of dominant discourses and striving for their reconfiguration (Johnson, 2006). The initial phase of this process can be traced back to 1975, when Mas'ud Zavarzadeh first introduced the term "*metamodernism*" to describe literary works that transcended the boundaries of modernism and postmodernism (Zavarzadeh, 1975). Although this concept did not immediately gain broad acceptance, various intellectual currents sporadically revived it in subsequent decades, resulting in a plurality of interpretations within scholarly discourse (Carruth, 1986; Haig, 1991; Koutselini, 1997; James, Seshagiri, 2014).

According to Knudsen (2016), the first signs of the exhaustion of postmodernism as the dominant cultural paradigm emerged in the 1990s. David Foster Wallace, in his essay *E Unibus Pluram* (1993), critically reflected on the implosion of postmodern irony, which had transformed from a tool for critiquing and demystifying power and hegemonic narratives into a mechanism that hindered authentic expression and emotional connection. Wallace thus disrupted the epistemological framework of postmodernism by articulating the need for a return to sincerity, engagement, and emotional truth—elements that can be regarded as early indications of a metamodernist stance (Knudsen, 2016).

Metamodernism gradually entered philosophical and academic discourse, a progression that can be identified as the autonomization phase within the Latour-Barnes model. Feldman (2005) contributed to this by constructing a theoretical triangulation between Gadamer, Habermas, and Derrida, thus suggesting the possibility of epistemological mediation between modernist rationality and postmodern skepticism. Feldman argued that although these philosophers often criticized one another and their philosophies were perceived as incompatible and intransitive, they actually shared certain epistemological and methodological foundations. Feldman conceptualized an interpretative triangle,

with each philosopher representing a distinct pole of critical interpretation, yet all operating within a metamodernist framework (Feldman 2005).

For our considerations, the first part of Feldman's article is particularly relevant, wherein he defines metamodernism and distinguishes it from both modernism and antimodernism. His analysis follows three main lines: a critique of modernism, a rejection of postmodern relativism and antimodernism, and the delineation of metamodernism as a middle path between these extremes. Feldman described metamodernism as a more moderate and productive alternative to modernism and postmodernism. His political strategy moved from critique to outright rejection. He criticized modernism for its reliance on subject-object metaphysics and epistemological foundationalism, which presuppose fixed, objective grounds of knowledge. He argued that if the subject cannot reliably connect with the objective world, such a model leads to either epistemological uncertainty or to relativism and nihilism. Postmodernism, on the other hand, was critiqued for its tendency to descend into radical relativism and antimodernism, wherein truth and knowledge are perceived solely as constructs of power, lacking the potential for objective or intersubjective validation. This, according to Feldman, disqualifies any form of critical discourse (Feldman 2005).

Feldman coined the term "metamodernism" to avoid the negative connotations and ambiguities associated with postmodernism, while simultaneously needing a term that reflected the transcendence (meta) of modernism and postmodernism. Metamodernism, as he defined it, embodies a synthesis of elements from both traditions—rejecting the rigid rationality and epistemological foundationalism of modernism while distancing itself from the extreme relativism and skepticism of postmodernism. The term thus emphasizes the dynamic oscillation between these frameworks, seeking a balance between engaged truth-seeking and the critical deconstruction of dogmas. Feldman acknowledged the situatedness of knowledge within context but maintained that forms of understanding could be attained that are not purely arbitrary (Feldman 2005).

Moreover, Feldman aligned his interpretation of metamodernism with Kuhn's concept of paradigmatic shifts, arguing that metamodernism represents a new philosophical framework akin to scientific paradigms in Kuhn's theory. It shapes our understanding of the world without relying on the objective epistemological foundations of modernism or the extreme relativism of postmodernism. Metamodernism thus emerges as a paradigm seeking equilibrium between certainty and uncertainty, tradition and innovation, interpretation and critique. His concept is dynamic, grounded in continuous oscillation between various epistemological positions, which is a key characteristic of metamodernist thinking (Feldman, 2005).

Feldman's decision to adopt this concept was inspired by Kuhn, Gadamer, Habermas, and Derrida. From Kuhn, he embraced the notion that knowledge

does not progress linearly but undergoes discontinuous transitions between paradigms, creating a dynamic oscillation among interpretations of reality. Gadamer's concept of the fusion of horizons led to the idea that knowledge and interpretation oscillate between subjective prejudices and the objective influences of tradition, emphasizing the significance of dialogue in individual and collective understanding. Habermas's theory of communicative action was particularly inspiring in terms of the communicative model of truth, which oscillates between individual convictions and universal norms of rational discourse. Derrida's deconstruction influenced Feldman's focus on meaning as non-fixed, oscillating between various interpretive frameworks depending on context and linguistic hierarchies (Feldman, 2005).

Feldman's approach, in Latourian terms, became part of the "circulation of references," wherein theoretical frameworks were iteratively modified, accumulating new interpretations until the explicit synthesis of metamodernism was generated. Although Feldman's article did not immediately garner broad acceptance, his work became an integral component of the scholarly argumentation that subsequently shaped and advanced the discourse on metamodernism.

The definitive breakthrough in the academic discourse on metamodernism was marked by the publication of *Notes on Metamodernism* by Vermeulen and van den Akker (2010), a key text that codified metamodernism as a recognizable paradigmatic configuration. The authors acknowledged that the term "metamodernism" had previously been employed in various works; however, they emphasized that their conceptualization was neither derivative nor directly influenced by these earlier usages (Vermeulen, van den Akker, 2010, p. 76). According to them, the prefix "meta" encapsulates three meanings that characterize the essence of metamodernism: *„epistemologically within (post)modernism, ontologically between (post)modernism, and historically beyond (post)modernism*" (Vermeulen, van den Akker, 2010, p. 57).

Vermeulen and van den Akker employed a political strategy of critique toward the declining postmodernism, arguing that its dominant strategies—irony, relativism, and deconstruction—were no longer sufficient for explaining contemporary cultural, aesthetic, and philosophical phenomena. Instead of advocating a definitive return to modernism or persisting within postmodern fragmentation, they defined metamodernism as a "*structure of feeling*", a concept originally derived from R. Williams (1977). However, they reinterpreted this notion: while Williams, grounded in historical materialism, saw emergent cultural forms as indicators of transitional periods not yet fully articulated as dominant ideologies, Vermeulen and van den Akker (2010) understood the "structure of feeling" in the context of oscillation between modernism and postmodernism.

They posited that the contemporary "structure of feeling" is not merely a transitory phase but rather a persistent oscillation between opposites—idealism

and skepticism, engagement and irony, hope and melancholy. The concept of oscillation thus becomes central to their articulation of metamodernism, capturing the fundamental dynamics of this paradigm. This oscillation is conceived not as a compromise or synthesis but as a dynamic movement, wherein the metamodern subject continuously navigates between opposing poles without definitively anchoring in either. Hence, metamodernism is neither a return to modernism nor an extension of postmodernism but an ongoing movement between these poles (Vermeulen and van den Akker 2010).

Metamodernism, as conceptualized by Vermeulen and van den Akker, does not reject the notion of truth but perceives it as an ever-evolving concept. It acknowledges the possibility of knowledge while recognizing its limitations—for instance, scientific methods are useful but cannot unveil all aspects of reality. Modernism aspired to one ultimate truth, postmodernism dismissed truth entirely, whereas metamodernism embraces a plurality of truths, seeking a balance between facts and interpretations. This approach facilitates a pragmatic engagement with truth, framing knowledge as an ongoing process of negotiation and interpretation. It underscores the plurality and contextualization of knowledge while encouraging dialogue between contradictory perspectives without insisting on definitive resolutions. It accepts truths as provisional, acknowledging their inherent uncertainty (Vermeulen and van den Akker (2010).

This epistemology is characterized by the "as-if" approach, derived from Kant's concept of negative idealism. The "as-if" epistemology allows for action and belief in certain values or ideals, even while acknowledging their uncertainty or unattainability. It embodies a cultural and societal behavior where meaning, truth, or progress are approached "as if" they were attainable, despite awareness of their elusiveness. This oscillatory epistemology distinguishes metamodernism from naive modern idealism, which fully believes in absolute truths, and from postmodern skepticism, which entirely denies them. The "as-if" epistemology, combined with the concept of oscillation, enables the metamodern subject to navigate between opposing positions without definitive settlement—constantly reevaluating possibilities (Vermeulen and van den Akker 2010).

This notion also relates to the ontological concept of *metaxy* [1](being-in-between), which the authors associate with philosophical traditions from Plato to Eric Voegelin. In metamodernism, *metaxy* is not interpreted as a static "in-between" but as a dynamic state of being simultaneously here and there, experiencing tension between opposites. This tension is central to metamodernism, allowing for continuous oscillation and dialogue rather than final resolutions or outright rejections. It reflects the fundamental nature of reality, characterized by constant

1 the term originates from the Greek expression μεταξύ (metaxý), which literally means "between" or "in the middle." (Vermeulen and van den Akker 2010).

negotiation between dichotomies such as hope and skepticism, engagement and irony, idealism and realism. This dynamic oscillation is ontologically rooted, emphasizing that reality is not fixed but persistently fluctuates between opposing extremes (Vermeulen and van den Akker 2010).

According to Vermeulen and van den Akker, metamodernism is not merely a descriptive category but a theoretical strategy that facilitates the understanding of renewed engagement and meaning-making in an era marked by uncertainties. It is a fluid yet crucial concept that reflects a contemporary world overwhelmed by uncertainty yet driven by a desire to reinstate grand narratives—not in an absolute sense but within a critically aware, oscillatory framework (Vermeulen and van den Akker 2010).

The reasons behind the broader success of Vermeulen and van den Akker's (2010) introduction of metamodernism into academic discourse—especially when compared to Feldman (2005)—can be attributed to several factors. Feldman's work is academically demanding, characterized by complex philosophical language, and primarily intended for specialists in philosophy and legal theory. By contrast, Vermeulen and van den Akker offered a more accessible and intuitive explanation of metamodernism, making the concept easier to grasp for both academic and non-academic audiences.

Timing also played a crucial role. Feldman's work emerged in 2005, at a time when academic debates concerning post-postmodernism were still nascent. Vermeulen and van den Akker published their essay in 2010, a period when there was already a broader demand for theories capable of supplanting postmodernism. Additionally, they launched the online platform *"Notes on Metamodernism"*, where they began publishing further texts and analyses regarding metamodernism in art, architecture, literature, and popular culture, thereby accelerating the discourse.

Five years later, Vermeulen and van den Akker (2015) revisited their initial article, noting that interpretations of metamodernism had since diversified and encountered various misunderstandings. They emphasized that metamodernism should not be understood merely as a philosophy, aesthetic movement, political program, or literary technique. They rejected interpretations that framed metamodernism as a manifesto, utopian vision, or a new mode of thinking to be prescriptively followed. Expressing concern over such misinterpretations, they clarified that their intention was to describe, not prescribe (Vermeulen and van den Akker 2015).

According to them, metamodernism is best conceptualized as a "structure of feeling," representing a widely shared sensibility that cannot be reduced to a singular strategy. It is not about synthesizing opposites but about consciously oscillating between them. They opposed views portraying metamodernism as a harmonizing principle, asserting instead that the dominant sensibility of contemporary culture is characterized by constant oscillation and paradox. Metamodernism, therefore,

is not a harmonious synthesis but a tension between contradictions. They linked metamodernism to responses to the economic, ecological, and political crises of the 21st century, perceiving it as a cultural logic that offers new ways of thinking and reacting to contemporary challenges, including environmental threats and growing social inequality (Vermeulen, van den Akker, 2015).

This position reveals the promising potential of metamodernism for geographical thought, which has traditionally cultivated an investigative approach to understanding complex phenomena and seeking practical solutions in zones of intense interaction between natural environments and human societies. The emerging challenges of the Anthropocene polycrisis, for instance, represent a pertinent research agenda for geography (Matlovič, Matlovičová, 2024).

A significant contribution to the academic discourse on metamodernism is represented by the two editions of L. R. Andersen's works (2019, 2023). Andersen distinguishes between the concepts of *metamodernity* and *metamodernism*. While she understands metamodernism as an artistic and cultural movement primarily associated with aesthetics, literature, film, and contemporary art, she conceptualizes metamodernity as a broader framework of social, political, and philosophical thought, capable of shaping new political, economic, and cultural systems. Metamodernity is envisioned as an attempt to reconstruct a society capable of addressing the challenges of the 21st century. It encompasses ecological, social, and economic issues and proposes the integration of the most valuable elements from past epochs—indigenous, pre-modern, modern, and postmodern. Metamodernity aspires to transcend mere artistic expression by creating a practical framework for societal development. In this sense, Andersen perceives it as more "realistic" and politically relevant than metamodernism itself (Andersen, 2019).

In the second edition of her book, Andersen (2023) opted to rename metamodernity to *polymodernity*, although the substantive content of the book remained largely unchanged. This renaming reflects her attempt to better capture the complexity of contemporary realities. It is debatable whether this change constitutes a case of conceptual redundancy. The title modification can be interpreted as an attempt to rebrand the book to make it more attractive to a wider audience, while the core content remains essentially the same. In line with Agnew (2012), this could be seen as a fanonian response to the already established concept of metamodernism.

Stoev (2022) also contributed to the conceptualization of metamodernism and metamodernity. He interprets metamodernism as an aesthetic and axiological framework that synthesizes modernist and postmodernist elements, while metamodernity is understood as a broader cultural and historical era that transcends postmodernism and reflects new forms of thinking and aesthetics. Similarly, Nachaeva (2021) presents a perspective on metamodernism as a new

anthropological myth that integrates diverse cultural, ethical, and aesthetic dimensions. She argues that metamodernism offers an understanding of reality and subjectivity through the experience of the "other Self" (*affication*). This process implies that a subject comprehends their identity through empathy and the experiences of others, marking a step towards the restoration of ontological grounding. This return to ontology is framed as a theoretical effort to overcome the relativism inherent in postmodern discourse (Nachaeva, 2021).

As metamodernism gradually gained supporters, it also provoked criticism, particularly from orthodox postmodernists who employed the politics of denunciation and rejection. They labeled metamodernism as a "reactionary" or "neosentimental project" that undermines the deconstructive strategies of postmodernism. Such arguments appeared predominantly in responses to the seminal works of Vermeulen and van den Akker (2010). Murphy (2017) criticized metamodernism as an academic construct, contending that it was not a natural consequence of artistic evolution but rather the result of actively "assembling" disparate works into a unified framework. He argues that just as Kafka created a new literary style, Vermeulen and van den Akker constructed metamodernism not by uncovering an existing artistic tendency but through interpretation. According to Murphy, metamodernism only became a tangible concept after being named, with artists subsequently creating works consciously within its framework (Murphy, 2017).

Murray (2021) focused his critique on the concept of oscillation, suggesting that oscillating between complexity and simplicity is insufficient. Merely alternating perspectives or "wavering" between opposites (e.g., rationality and spirituality, systemic thinking and holism) does not address deeper processes of shedding harmful layers of complexity and returning to fundamental, robust foundations (e.g., spiritual values, ethics, intuition). Modern culture often assumes that complex problems require more complexity for resolution, but Murray warns that sometimes the solution lies in embracing simplicity—not oscillating between extremes but eliminating unnecessary layers of knowledge or belief systems. He posits that while oscillation may be a useful aspect of metamodern thought, it should not be regarded as the sole mechanism for development. Genuine transformation, he argues, also requires releasing redundant complexity, confronting shadow elements, and returning to core values (Murray, 2021).

Shullenberger (2020) highlighted paradoxes related to the transformation of metamodernism from an aesthetic concept into a political ideology oscillating between conviction and performative irony, especially during the first Trump era. In this context, he referenced Abramson's (2016) attempt to interpret Trump's candidacy through the lens of metamodernism. Abramson argued that Trump was not merely a product of cynical populism or media culture but represented a new type of politician who strategically oscillates between

idealism and manipulation, self-irony and sincerity. Abramson anticipated that Trump's political style would have long-term implications for American politics, as later confirmed by Trump's second presidential victory in 2024. He contended that Trump is not a postmodern politician whose sole aim is the deconstruction of political norms, but rather a "metamodern politician"—an individual oscillating between idealism and cynicism, authenticity and self-irony, while maintaining belief in a personal metanarrative despite its controversial nature. This combination of confidence and self-reflection is, according to Abramson, characteristic of the metamodern approach to politics (Abramson, 2016).

Shullenberger (2020) critiqued Abramson by pointing out that subsequent updates to Abramson's blog propagated the narrative that Trump was merely a product of Russian interference in the U.S. elections. Shullenberger argued that this shift abandoned the metamodern perspective on Trump, instead embracing a rigid, moralizing interpretation of political reality (Shullenberger, 2020).

In response to such resistance, the *politics of adaptation* allowed certain academic groups to pragmatically integrate metamodernism into existing disciplines without presenting it as a radically divergent concept. Subsequently, the *politics of unification* was applied, portraying metamodernism not as an opposition to postmodernism but as a synthetic concept capable of preserving its critical potential while opening space for new forms of engagement and authenticity. This strategy proved particularly crucial for its acceptance in interdisciplinary discussions concerning epistemology and ontology.

The next section of this contribution will focus on further elaborating this developmental trajectory.

OSCILLATING FRAMEWORKS: THE RECEPTION OF METAMODERNISM IN SCIENTIFIC DISCOURSES

Following the initial phase of mobilization, the autonomization phase ensues, characterized by systematic engagement with the scientific community to expand and establish the new epistemological framework. The reception of metamodernism in scientific literature has evolved from an initial focus on aesthetics and culture to a broader interdisciplinary framework encompassing the philosophy of science, as well as the natural, social, and humanities disciplines. This discourse has yielded numerous valuable insights, including significant implications for geographical thought.

A central theme within this discourse is the association of the contemporary crisis in the social sciences with the exhaustion of the postmodernist discourse. Pipere and Mārtinsone (2022) argue that postmodernism has led to excessive fragmentation and relativization of knowledge, impeding the formulation of a cohesive framework for research and social praxis. In this context, metamodernism

is presented as a potential avenue for restoring balance between skepticism and idealism. As conceptualized by the authors, metamodernism does not represent a return to outdated paradigms but rather establishes a new, dynamic framework in which diverse perspectives and methodologies complement one another (Pipere and Mārtinsone, 2022).

This approach carries practical implications for research, particularly concerning mixed-methods studies, interdisciplinary approaches, and inclusive knowledge production. The authors dedicate considerable attention to the application of the metamodernist framework within specific fields of research, including education, psychology, social policy, and ethics. They highlight that metamodernism facilitates innovative ways to tackle complex challenges like polycrisis. The authors not only analyze metamodernism but also actively advocate for it as a superior alternative to postmodernism (Pipere, Mārtinsone, 2022).

In a subsequent publication, Pipere and Mārtinsone (2023) extend the application of the metamodernist framework to encompass all branches of contemporary science, including the natural sciences, social sciences, and humanities. They explore how the epistemological and ontological principles of metamodernism influence scientific thinking, scientific truth, and interdisciplinary collaboration. Drawing upon diverse philosophical approaches and theoretical frameworks—including metamodernist philosophy, post-normal science, systems theory, and digital innovation—they identify six key principles of metamodernism relevant to scientific inquiry (Pipere, Mārtinsone, 2023).

A significant contribution to the reception of metamodernism in the study of religion and other humanities is provided by Storm (2021, 2025). In his works, Storm introduces several key concepts aimed at encompassing a wide range of philosophical disciplines within his metamodernist project. Central to his approach is the incorporation of the metamodernist principle of *oscillation*, understood as a continuous dynamic between opposing poles. Rather than resolving this tension through synthesis or definitive conclusions, Storm emphasizes the productive engagement with these oppositions. This principle permeates his entire body of work, shaping his approach to philosophy, epistemology, ontology, ethics, and semiotics.

In the subsequent sections, we will provide a more detailed discussion of the key metamodernist principles and concepts, highlighting their potential for reception within the ontological, epistemological, methodological, and ethical dimensions of geographical thought.

METAMODERNIST CONCEPTS AND PRINCIPLES AND THEIR RECEPTION IN GEOGRAPHICAL THOUGHT

Metarealism – The Multilayered Nature of Geographical Metareality

According to Storm (2021), the foundational philosophical premise of metamodernism is *metarealism*, which offers a novel approach to conceptualizing reality and existence. Rather than adhering to binary categorizations, metarealism proposes a multilayered understanding of reality. To support this perspective, Storm introduces the concepts of *modes of reality* and *contrastive classes* as essential tools for comprehending how reality is defined and categorized. Reality, from this perspective, does not possess a singular or uniform mode of existence but rather consists of multiple "modes" or forms of being, contingent upon the specific type of phenomenon in question. Each phenomenon can be deemed "real" within a particular context while simultaneously being perceived as "non-real" within another (Storm, 2021).

Storm emphasizes that the term "real" acquires significance only in contrast to something considered "non-real." Therefore, it becomes necessary to specify the *contrastive class*—that is, the framework within which something is identified as "non-real"—when labeling any entity as "real." This approach helps clarify vague or misleading conceptualizations of reality. Storm's metarealism oscillates between these poles, rejecting dogmatic interpretations of reality as either purely objective or purely constructed (Storm, 2021).

Enriching this discussion is the concept of ontological stratalism introduced by Dziadkowiec (2015). Ontological stratalism, as conceptualized by this author, represents an integrative philosophical framework that explores the layered structure of reality. This framework draws upon a diverse array of theoretical and philosophical traditions, including British emergentism, general systems theory, complexity theory, G. Ellis's four-worlds concept, Hartmann's ontological theory of stratification, and Whitehead's processual philosophy. Despite their distinct approaches, these perspectives share a fundamental concern with the stratified organization of the world. In its broad conceptualization, stratalism encompasses all theoretical frameworks where the notions of layers or hierarchical structures of being play a significant role. Within this context, elements of stratalist thinking can be identified in British emergentism, Hartmann's stratified ontology, complexity theory, and general systems theory. All of these perspectives acknowledges that reality is organized into distinct yet interrelated levels, emphasizing the importance of analyzing how these levels interact and contribute to the emergence of complex phenomena. In its narrower definition, ontological stratalism is framed as a philosophical stance positing that the world consists of a hierarchically layered structure, characterized by successive, partially distinct strata or levels of being. These layers are defined by specific intra-layer structures,

inter-layer relationships, and entities that transition or interact across these layers (Dziadkowiec, 2015, p. 8).

The core focus of ontological stratalism is on addressing four fundamental problems:

a) definition of layers: understanding the nature and criteria that define distinct layers of reality.
b) structure of layers: analyzing the internal organization and properties that characterize each layer.
c) inter-layer relationships: investigating the dynamic interactions and causal relationships between layers.
d) hierarchy of layers: exploring the ordering and hierarchical arrangement of layers in the structure of reality.

The originality of this concept lies in its deliberate positioning between two extreme ontological stances: reductionist monism (particularly physicalism), which attempts to explain all phenomena by reducing them to fundamental physical processes, and isolationist pluralism (e.g., occasionalism), which treats layers of reality as entirely separate and non-interacting domains. By rejecting both extremes, stratalism advocates for an intermediate approach, acknowledging the distinctiveness of layers while recognizing their interconnectivity and mutual influence. This perspective allows for a more nuanced understanding of reality, where complexity and hierarchy are seen as emergent and interdependent (Dziadkowiec, 2015).

He further emphasizes that integrating the conceptual apparatus of Whitehead's processual philosophy can provide ontological stratalism with a dynamic and diachronic dimension. This inclusion enriches stratalism by framing layers not as static entities but as processes that evolve and interact over time. Whitehead's processual insights contribute to understanding how entities transition across layers, how complexity unfolds, and how dynamic interplays shape the stratified reality Dziadkowiec (2015, p. 248).

Ontological stratalism, when approached through a metamodernist lens, emerges as a dynamic and integrative framework that oscillates between the poles of hierarchical structure and fluid interconnectivity. It embraces the layered complexity of reality, acknowledging both the stability of stratified orders and the transformative potential of inter-layer interactions. In this sense, ontological stratalism does not merely provide a map of reality but becomes an active methodology for exploring the interplay between order and chaos, stability and change, simplicity and complexity. It holds the potential to inspire interdisciplinary dialogues and methodological innovations that honor the plurality of perspectives while seeking coherence within diversity. This oscillatory stance offers a fertile ground for philosophical reflection, encouraging continuous movement between

questioning and meaning-making, uncertainty and insight, and ultimately, between the known and the possible.

From a metamodernist perspective, rigid disciplinary boundaries are rejected in favor of a dynamic reconceptualization of the object of inquiry. Applying the principles of metarealism to the Earth's *landscape sphere*—the core object of geographical inquiry (see Matlovič, 2006)—allows for its interpretation as a *multilayered metareality*, oscillating between diverse modes of existence. These modes depend on both context and epistemological approach.

In this framework, the object of geographical inquiry is not a static assemblage of geospheres but rather a continuously evolving structure of interactions oscillating between the material and immaterial, the physical and the social, the virtual and the conceptual. Thus, the Earth's landscape sphere manifests not merely as a material system but also as a mental and social construction. Geographical inquiry, therefore, oscillates between these diverse modes of understanding.

This perspective encourages the integration of natural, social, cultural, technological, noospheric, and cyberspheric dimensions of the Earth's landscape sphere (Matlovič, 2006), facilitating scientific inquiry that transcends rigid dichotomies between objective and subjective knowledge. Consequently, it promotes a dynamic, context-sensitive, and integrative approach to geographical research, aligning with the metamodernist principle of oscillation and the rejection of fixed epistemological frameworks.

Anchoring Reality: The Dynamics of Natural and Social Kinds

Metarealism addresses the relationship between objective and constructed reality through the concept of *contrastive classes*—nothing is inherently real but only in contrast to something else. This perspective enables geography and the social sciences to transcend postmodern skepticism towards objective phenomena without reverting to rigid realism. The *theory of social kinds* offers a mechanism for both stability and transformation, demonstrating how social categories are formed, altered, and reproduced through anchoring processes. According to Storm (2021), this theory forms the foundation of metamodernist ontology. The author aims to replace exhausted and unproductive postmodern approaches, particularly the dominance of discursive studies. He extends the analysis of social phenomena beyond the confines of language and discourse to understand their material causes and consequences.

In Storm's view, metamodernism must integrate linguistic analyses with examinations of material, social, and environmental factors. The proposed solution is a framework of *processual social ontology*, representing a shift from essentialist thinking towards a dynamic, process-oriented perspective on reality. Storm conceptualizes *natural kinds* and *social kinds*, integrating them into this framework, which emphasizes the dynamic and interconnected nature of reality (Storm, 2021).

Natural kinds are categories that reflect an objective, relatively stable, and "natural" structure of reality. These entities or phenomena exist independently of human activity, context, or perception. They are typically studied and interpreted through the natural sciences, which rely on empirically verifiable facts. Although natural kinds are regarded as "natural" and objective, their classification can be partially influenced by human discourse and practical needs (Storm, 2021).

Social kinds are categories that emerge through human activity, social interactions, and historical-cultural contexts. They are characterized by variability and constant change, lacking stable or universal properties. Their meaning is fluid and shifts depending on geographic, historical, socio-economic, political, and cultural contexts. These are entities whose existence depends on human beliefs, linguistic constructions, social practices, and material conditions. They are continuously sustained, modified, and reconstructed through social interactions and material activities. Their properties are neither inherent nor fixed but represent constellations of characteristics that depend on ongoing negotiations between social actors, material conditions, and cultural patterns. This *relational ontology* rejects essentialism and the isolated understanding of entities, which is particularly useful for studying complex phenomena explored by geography (Storm, 2021).

Storm defines social kinds as *temporary zones of stability* within constantly evolving processes, anchored in material reality and social interactions. These kinds can include artifacts (e.g., hammers, money), social roles (e.g., professor, Buddhist monk), norms, events, and institutions. Storm adopts the concept of *homeostatic property clusters* from philosopher Richard Boyd, who defines natural kinds as clusters of properties maintained by stable causal mechanisms. However, Storm adapts this model to social kinds, conceptualizing them as dynamic *clusters of powers* rather than static properties. These powers reflect the potential of entities to act or be acted upon within specific contexts. Storm distinguishes between actualized powers – actual properties observable at a given time; and potential powers – properties that may manifest under specific circumstances. Powers can be advantageous (abilities) – contributing positively to the stability or reproduction of social kinds, and disadvantageous (liabilities) – contributing negatively, potentially undermining the sustainability of social kinds (Storm, 2021).

Social kinds exhibit both *homeostatic* and *heterostatic* mechanisms that maintain stability and variability within the kind. Storm (2021) focuses on the *causal processes* that anchor and stabilize the properties and powers within social kinds, thereby ensuring their sustainability and reproduction. The author identifies three fundamental types of these anchoring processes.

Dynamic-nominalist anchoring occurs when social kinds acquire shared properties through naming, classification, and subsequent role adoption. This process involves the continuous creation and maintenance of categories via discourse, norms, and authoritative decisions. Importantly, these categories are

not entirely arbitrary; rather, they reflect specific social and material conditions. Dynamic-nominalist processes emphasize the *power of naming*, which not only mirrors reality but also normatively and politically shapes it. For such processes to function effectively, they must be supported by institutional and legal mechanisms that reinforce the authority of classifications and roles (Storm, 2021).

Mimetic anchoring refers to the imitation and dissemination of social practices, economic models, cultural trends, political strategies, and societal values. These processes highlight how social kinds replicate and stabilize through cultural and social mimicry. For instance, the adoption of specific economic systems, fashion trends, or governance models across societies exemplifies how social categories can propagate through imitation. This process ensures that certain social kinds persist and expand their influence over time (Storm, 2021).

Ergonic anchoring explains why social kinds may share similar properties, even if they originated independently, due to their design to fulfill identical functions. This type of anchoring involves *physical, natural, material, and technological processes* that contribute to the formation and maintenance of social categories, such as infrastructure or technology. Anchoring, in this context, is based on *functional selection and design*—for example, the structure of currency systems, the architectural templates of global hotel chains, the layout of airport terminals, the algorithmic frameworks of navigation apps, the spatial configuration of logistics hubs, the interoperable infrastructures of data centers and server farms or the standardized design of fast-food restaurants. These designs are selected and stabilized according to their capacity to meet specific functional needs (Storm, 2021).

Storm's framework of anchoring processes offers a comprehensive understanding of how social kinds are dynamically formed and stabilized. By distinguishing between dynamic-nominalist, mimetic, and ergonic anchoring, he illustrates the complex interplay of discursive, cultural, material, and functional factors that shape social reality. His approach enables the deconstruction of existing social constructs and provides a pathway for their reconstruction within new socio-material contexts. Storm introduces the concepts of *deconstruction* and *reconstruction* to elucidate how social kinds are formed, transformed, and stabilized.

Deconstruction refers to the analytical process of examining how social kinds emerge and function while stripping them of essentialist and immutable status. It involves uncovering the historical, social, and material conditions that have contributed to their current formation. Empirical reconstruction involves the investigation of specific *power-clusters*—the sets of properties that characterize a social kind—and analyzing the anchoring processes that stabilize them. This process seeks to understand how social kinds maintain their coherence and continuity over time. Normative reconstruction occurs when scholars

advocate for the reinterpretation or redefinition of social kinds, proposing new conceptualizations and uses for these categories within academic or social contexts (Storm, 2021).

Social kinds, therefore, represent *dynamic, processual clusters* of properties and powers that gain stability through various anchoring mechanisms. Storm's distinction between *natural* and *social kinds* provides a robust framework for understanding reality as a dynamic interaction of objective natural processes and historical-cultural constructions. This integration is fundamental to his metamodernist approach, which seeks to transcend binary oppositions between the natural and social worlds by unifying them in a dynamic process of interaction.

From the perspective of geographical thought, the integration of *metarealism* and the *theory of social kinds* enables the conceptualization of space as a dynamic configuration of social and material interactions. These interactions oscillate between *relative stability*—such as state borders or urban structures—and *continuous transformation*, such as the evolving social identities of cities or the development of technological networks.

Storm's (2021) theory of social kinds introduces an innovative ontological framework for defining geographic objects. It overcomes the traditional dualism between natural and social phenomena by interpreting them as *dynamic, processually anchored structures* that oscillate between stability and transformation. This approach facilitates the integration of material (natural) and social factors into a more comprehensive geographical understanding. Natural kinds represent ontologically more stable categories of geographical investigation, as they are determined by natural laws. However, their classification and interpretation can be influenced by social constructs. Although natural kinds exist independently of human perception, their social significance and utilization oscillate depending on context. For example, mountain ranges may be perceived as natural barriers, sacred spaces, or economic resources (e.g., tourism, mineral extraction, forestry). Thus, the meaning attributed to these physical features is shaped by cultural, economic, and political narratives.

In contrast, social kinds are *dynamic categories* emerging through human activity, political decisions, and cultural processes. Their existence is not inherent but is stabilized through anchoring mechanisms. For instance, state borders are not natural entities but are social kinds anchored by legal norms, geopolitical agreements, and physical infrastructure such as walls, fences, or customs checkpoints. Social kinds also oscillate between *local and global narratives*, as well as between historical traditions and emerging narratives. For instance, the concept of "Europe" encompasses geographical space, cultural identity, political projects, economic zones, and historical constructs that have evolved over time (e.g., Jensen, Richardson, 2004). The fluidity of this concept reflects the dynamic nature of social kinds and their continual negotiation through anchoring processes.

Anchoring processes are mechanisms that stabilize geographic entities, enabling them to persist despite their inherently dynamic character. Storm (2021) identifies three principal types of anchoring that can be applied to geographical thought. Dynamic-nominalist anchoring stabilizes entities through *naming and classification*. Geographic concepts such as "Central Europe" or "Post-Soviet Space" emerge from historical, political, and discursive processes. These names help stabilize perceptions of space, although their meanings can change over time. For example, while *Czechoslovakia* no longer exists as a political entity, it persists in cultural memory as a historical and discursive construct. Maps serve as key instruments of nominalist anchoring, translating spatial realities into stable categories despite their constant transformation. Mimetic anchoring occurs through the imitation and replication of spatial patterns. For example, urban planning models such as the "*15-minute city*" (e.g., Mocák et al., 2022) have been replicated across various cities through processes of mimicry. Similarly, economic models—such as China's exportation of infrastructure projects to Africa—contribute to the formation of new geographic structures (e.g., Taylor, Zajontz, 2020). Cultural norms also replicate spatial perceptions; for instance, the ideal of "suburbia" as a desirable form of living originated in the United States but has influenced urban development across Europe and Asia (e.g., Clapson, Hutchison, 2010). Ergonic anchoring is achieved through material infrastructure. For example, *cyberspace* is anchored in physical data centers and computational infrastructures (e.g., Hristova et al., 2022). Despite its seemingly intangible nature, it continuously reconfigures in response to technological innovation. This anchoring ensures that even the most fluid and dynamic forms of spatiality retain material grounding.

The integration of *metarealism* and the *theory of social kinds* in geographical analysis offers a robust framework for overcoming the dichotomy between physical and social space. It provides an analytical lens that integrates *natural, social, technological, and symbolic dimensions* of geographic reality. This perspective enables the study of how space is formed, stabilized, oscillated, and reconfigured within global-local interactions.

Embracing Uncertainty: Zetetism in Metamodern Epistemology

The concept of *zetetism*[2], as articulated by Storm (2021), represents an epistemology that integrates skepticism with productive and practically oriented knowledge. In contrast to postmodern skepticism, zetetism extends its critical lens to skepticism itself, highlighting that while radical doubt is always possible, such doubt holds limited value if it does not lead to improved differentiation between more

2 A term derived from the Greek word **ζητητικός (zētētikós)**, which means "one who seeks" or "one who investigates." It originates from the root **ζητέω (zēteō)** – "to search," "to inquire," or "to strive for understanding." (Storm, 2021).

and less probable claims. Thus, zetetism replaces "paralyzing doubt" with *modest yet effective knowledge*—knowledge that is aware of its limitations yet remains committed to deepening our understanding of reality (Storm, 2021).

A pivotal element of Storm's argument is the association of zetetism with *abductive reasoning* (inference to the best explanation). Storm asserts that abduction offers a model of progressive knowledge development that is more resilient to skepticism than inductive generalization. Abduction allows for a *cumulative increase in certainty*: when a hypothesis is progressively supported by multiple lines of evidence and alternative explanations are systematically excluded, it becomes increasingly robust, even though it may never achieve absolute certainty. This author argues that *intellectual progress is possible*, provided that knowledge is framed as provisional and open to revision. He rejects the notion of absolute certainty as an unrealistic epistemological standard, emphasizing that while anything may be questioned, not all claims are equally questionable. This approach fosters a nuanced and differentiated framework for evaluating knowledge claims (Storm, 2021).

Storm advances the concept of *"modest knowledge,"* which entails the recognition of potential error even in strongly supported beliefs. Zetetism, therefore, does not stand in opposition to knowledge but rather deepens critical thinking by demanding differentiated and precise analytical tools. It encourages scholars to embrace uncertainty as a natural aspect of inquiry while still striving for the best possible explanations and interpretations (Storm, 2021).

In the context of academic research, Storm underscores that in the absence of absolute certainty, the level of evidentiary rigor must be adjusted to the significance of the research question. This perspective bridges epistemology with *practical decision-making*, emphasizing that the process of inquiry must align with the pragmatic implications of knowledge claims. Hypotheses must be treated as provisional, predictions should be flexible, and multiple scenarios must be considered. Storm's zetetism emphasizes that knowledge is *processual*—a dynamic and evolving framework where conclusions are open to revision based on emerging evidence. This epistemological model is not merely theoretical but possesses significant *practical value* for addressing complex global challenges such as the climate crisis, migration, or social inequality. By advocating for flexible and context-sensitive approaches, zetetism contributes to the development of adaptive strategies that are capable of responding to the uncertainties inherent in contemporary global issues. In this sense, zetetism embodies an epistemological framework that combines intellectual humility with methodological rigor. It invites researchers and practitioners to embrace uncertainty not as a barrier to knowledge but as a condition for deeper inquiry and more sustainable problem-solving (Storm, 2021).

Based on zetetic principles that emphasize open, self-reflective, and practically oriented knowledge, a metamodernist reinterpretation of epistemology within geographical thought can be proposed. Geography is therefore not conceived as a rigid discipline with strictly defined boundaries but as a a dynamic field of knowledge that oscillates between paradigms while striving to identify the most plausible explanations within the context of an evolving reality.

Storm (2021) underscores the necessity of integrating doubt as a productive instrument of knowledge. In geographical research, this implies embracing *epistemic humility* and continuously scrutinizing established knowledge. Geography should deliberately employ *abductive reasoning*, which does not provide definitive or universal answers but seeks the most probable explanations of geographic phenomena based on available evidence. Knowledge is thereby understood as provisional, contextual, and open to revision.

Metamodern epistemology within geography rejects fixed paradigms and instead emerges as a post-disciplinary and post-paradigmatic science that eschews rigid separations between subdisciplines and incompatible paradigms. Instead, it emphasizes the dynamic interconnection of knowledge across disciplines and paradigms. This approach highlights oscillation between analytical and synthetic frameworks, perceiving geographical objects as *dynamic social kinds* whose identities are continually shaped by the interaction between natural processes and social practices. The post- prefix in "post-paradigmatic" signals that geographical thought does not adhere to a single dominant paradigm but rather integrates multiple paradigms in a reflexive way.

A geography grounded in zetetism operates within the conceptual space of *metaxy*—the oscillation between stability and transformation, between objective and subjective knowledge, and between universal and particular perspectives. Every research endeavor is conceptualized as a negotiation between various ontological and epistemological approaches, whereby geography reflects the complexity and fluidity of reality.

It is precisely within this oscillation that geography discovers its *epistemological strength*, enabling deeper and more nuanced understandings of the world. This perspective positions geography as an adaptive and reflexive discipline, capable of navigating the uncertainties and complexities inherent in contemporary global challenges.

In practical research contexts, the principle of *methodological pluralism* is applied to address the complexity of natural and social phenomena. Methodological pluralism is a key principle of metamodernism, which allows: to oscillate between different approaches, thus minimizing the limits of individual methods; to combine different insights and perspectives in order to understand complex phenomena in all their breadth and depth; and to open up space for interdisciplinary and transdisciplinary collaborations, thereby strengthening the

capacity of science to respond effectively to contemporary societal challenges (Pipere, Mārtinsone, 2023, pp. 18-19).

Instead of relying on a single analytical framework, metamodernist research oscillates between quantitative (statistical, GIS, machine learning) and qualitative (ethnographic, discourse analysis, participatory research) methods depending on the research context. Data should be continuously re-evaluated and questioned while remaining pragmatically useful for understanding spatial phenomena. Mixed methods enable researchers to explore these phenomena from multiple perspectives, thereby reducing the risk of one-sided interpretations. This approach requires scholars to possess both knowledge and flexibility across various methodologies, ensuring that they can employ them critically and reflectively. Such an approach necessitates a profound understanding not only of individual methods but also of their broader philosophical and epistemological contexts. Abduction allows researchers to generate the most plausible explanations based on incomplete information, avoiding modernist certainty and postmodernist skepticism.

For instance, in urban geography, research on *gentrification* and studying power dynamics may combine quantitative methods—such as statistical analysis of demographic changes and spatial analysis of property price variations—with qualitative approaches, including ethnographic interviews with residents and narrative analysis concerning perceptions of transformations. This combination allows for a more nuanced and holistic exploration of gentrification, capturing both its material impacts and subjective experiences (e.g., Drouet, Barrioz, 2024).

Metamodernism urges researchers to remain critically aware of the epistemological foundations underlying their chosen methods. It requires reflexive engagement with the limitations and assumptions underlying these methodologies. A pertinent example of reflexivity in geographical research involves the application of *big data* and *algorithmic analysis*. While such methods can yield valuable insights, they also necessitate a critical consideration of ethical concerns, including issues of digital surveillance, privacy, and the power structures embedded in algorithms (Varoufakis, 2024). Thus, metamodern methodological pluralism not only facilitates richer empirical insights but also promotes critical awareness and ethical responsibility in the practice of scientific inquiry.

Hylosemiotics: Bridging Materiality and Meaning in Geographic Inquiry

Storm formulates a metamodern theory of meaning, referred to as *hylosemiotics*[3]. He argues that semiotics (the study of signs) and ontology (the study of being) must be formulated conjointly, as meaning is never isolated from the physical

3 The term is derived from the Greek words: ὕλη (hylē) – meaning matter, material, or substance, and σημειωτική (sēmeiōtikē) – meaning the science of signs or semiotics

world. In contrast to postmodern skepticism, which reduces meaning to linguistic games and social constructs, hylosemiotics emphasizes that knowledge arises through active engagement with the world. The mind is not an isolated entity but a dynamic network of relationships among the body, external signs, and collective representations. Human beings, along with other entities, utilize the world as an extended cognitive memory, where meaning is not simply a subjective interpretation but something that emerges from materially grounded signs that facilitate coordination within both social and ecological systems. Hylosemiotics thus challenges radical linguistic relativism and the idea of translation as impossible, offering a new approach to analyzing culture, knowledge, and the semiotic nature of reality (Storm, 2021).

As evidenced in our preceding considerations, geography within the metamodern framework is conceptualized as a *post-paradigmatic discipline*. From this perspective, it is particularly productive to highlight that Storm (2021), through his hylosemiotic approach, re-evaluates Kuhn's concept of the incommensurability of paradigms. He builds upon the notion that reference and meaning are not fixed but arise in interaction with the material world through semiotic processes. Storm rejects Kuhn's strong notion of untranslatability and argues that scientific paradigms are not closed linguistic systems but emerge from the semiotic relationship between the world and its interpretation. He dismisses the idea that scientific terms have absolute referents that change with paradigm shifts. Instead, he proposes that reference is flexible and can follow *"property clusters."* This means that even when paradigms change, old and new concepts may overlap, allowing for at least partial translation. Scientific concepts are not rigid entities but are processes of inference and property clustering (Storm, 2021).

During paradigm shifts, scientists do not translate words directly but alter how they interpret *signs-aspects* of the world. This process is abductive (as in Peirce's semiotics), meaning that scientists reinterpret existing concepts to derive new meanings. If paradigms were entirely untranslatable, scientists could not engage in discussions or reconstruct past theories. Empirical testing (e.g., experiments, observations) serves as a semiotic anchor that enables comparisons across paradigms. Scientific paradigms are not linguistically incompatible islands but historically interconnected semiotic systems. Storm points out that even as language evolves, scientists can understand older theories and translate them into new frameworks. This hylosemiotic reconceptualization offers a realistic yet flexible perspective on the evolution of science, where meanings are not fixed but adapt through interaction with the material world (Storm, 2021).

From an epistemological perspective within geographical thought, the hylosemiotic approach enables a metamodern reinterpretation of the key geographic concept of *place* as a dynamic semiotic configuration. Here, material structures, social interactions, and value interpretations converge. This approach

integrates compositional, socio-constructivist, and substantive-axiological research perspectives into a coherent framework (see more in Matlovič, 2009).

Within the hylosemiotic framework, the compositional perspective involves the analysis and synthesis of spatio-temporal structures and forms of abiotic, biotic, and anthropogenic origins. These structures are perceived as dynamic semiotic configurations. The *geodiversity* of a given place arises from the coexistence and interaction of *physiospheric, technospheric, sociospheric*, and *noospheric-cyberspheric* components, all of which are carriers of both material and meaningful signs. Applying the compositional perspective involves predominantly empirical-analytical approaches, expanded by the examination of materially grounded semiotic processes. This approach facilitates understanding how physical and technological structures not only shape space but also carry meanings that influence their interpretation and perception within ecological and social systems.

The socio-constructivist and contextual perspective within hylosemiotics focuses on analyzing the position of the studied place through the interpretation of materially grounded semiotic interactions across various contexts. This perspective identifies and explains socio-spatial processes, mechanisms, actors, and networks, conceptualizing place as a dynamic semiotic configuration where material and meaningful flows intersect. Interactions between the place and its surroundings, as well as between macro- and local structures, are analyzed as processes of emergence, exchange, and transformation of signs and meanings that shape the daily experiences of actors. This approach primarily employs critical-analytical methodologies, enriched by the study of *semiotic anchors* and interpretative frameworks through which communities construct meaning in complex social, technological, and environmental networks.

The substantive-axiological perspective within the hylosemiotic framework concentrates on identifying and understanding dominant materially anchored meanings, identities, and values formed through semiotic interactions in the everyday efforts of local communities. This approach explores how meaningful dominants and value orientations manifest in specific material signs, spatial arrangements, and symbolic practices that define the community within space and time. The identity of place is thus understood as the result of dynamic interaction between the material environment, social practices, and cultural symbols that together create a meaningful framework for existence. Applying this perspective involves primarily hermeneutical methodologies, expanded by analyzing material signs and their meanings, with a focus on interpreting how communities anchor their values and identities through interaction with the physical and social environment.

The hylosemiotic approach, with its emphasis on the integration of material structures and semiotic processes, facilitates a nuanced understanding of *place* as a dynamic and multilayered phenomenon. This conceptualization allows for

the interpretation of geographic reality as an interactive and evolving semiotic landscape, wherein physical and social dimensions are intricately interconnected. It encourages geographical research that acknowledges the co-evolution of materiality and meaning, advancing analyses that reflect the complexity of spatial experiences within contemporary socio-ecological systems.

Such an approach not only broadens the analytical scope of geographical inquiry but also fosters reflexive awareness of how meanings are constructed and stabilized in relation to material conditions. This enables the development of methodologies capable of capturing the dynamic and oscillatory nature of geographic phenomena, thereby contributing to a more holistic understanding of spatial realities in the context of global transformations.

Sublation in Metamodern Thought: Reconciling Contradictions through Higher Synthesis

The concept of sublation within the context of the rise of metamodernism was emphasized by Vandevert (2025), who identified its deeper connection with Hegelian philosophy. Vandevert expands upon the traditional understanding of Hegel's triadic dialectic (*thesis – antithesis – synthesis*) by introducing a fourth stage, termed "absolute negation," which refers to the continuous repetition of transformative processes. He draws on Žižek's concept of the *negation of negation*, a central element of Hegelian dialectics. According to Žižek, the *negation of negation* is more than mere rejection—it is a process that transforms and reinterprets the original state, wherein negation is not the final goal but a means to ascend to a higher level of being and understanding. In the metamodernist framework, *negation of negation* implies that each new phase incorporates aspects of past epochs while overcoming and transforming them. This process culminates in *sublation* (*Aufhebung*), where opposites merge into a higher synthesis (Vandevert, 2025). Sublation, therefore, does not destroy the original concept but reformulates and elevates it to a higher level. It is a cyclical, never-ending process that continuously unites what has been alienated or separated.

Vandevert (2025) extends Hegel's concept of sublation to the oscillation between opposites (e.g., seriousness vs. irony, subjectivity vs. universality), asserting that metamodernism does not negate these dichotomies but integrates and transforms them. In metamodernism, sublation is intrinsically linked to three key elements:

a) Ironic Sincerity – an oscillation between irony and sincerity, which do not exclude each other but form a new, authentic mode of expression.
b) Becoming – a process of continuous transformation that does not aim for fixed truth but embraces a dynamic state of rediscovering the self and the world.

c) Self-Renewal – the ongoing reassessment of personal identity and position in the world through continuous introspection, leading to transformation at both individual and collective levels.

For Vandevert (2025), sublation is not merely about overcoming contradictions but also about integrating them into a higher whole. Postmodernist rejection of universal values, he argues, leads to a sense of anomie and stagnation. Metamodernism, by contrast, reevaluates and reconstructs these values in a new, flexible, and self-reflective form—one that acknowledges its limitations, embraces imperfection, and continuously seeks higher principles and meanings (Vandevert, 2025).

The metamodernist principle of sublation promotes a research methodology in geography that is both integrative and dynamic. For instance, the analysis of globalization and local cultural identities should not be approached through rigid dichotomies but through an understanding of how these identities continuously transform under the influence of global trends while maintaining local specificity. In environmental geography, the concept of *sublation* encourages strategies that recognize the cyclical and interdependent relationship between humans and natural systems. This includes acknowledging historical environmental degradation while fostering innovative practices for ecosystem restoration. In terms of urban geography, sublation can inform sustainable development models that integrate global design innovations with local cultural and environmental needs. Urban planning becomes a process of oscillation between global trends and local adaptations, ensuring that development is contextually relevant and ecologically responsible.

Just as science oscillates between irony and sincerity in metamodernism, geography oscillates between quantitative and qualitative approaches, with neither being inherently superior. For instance, in social geography, big data analytics (such as GIS analysis) are combined with ethnographic methods and narrative research to understand spatial behaviors and perceptions of landscapes from both subjective and objective perspectives (e.g., Kwan, Ding, 2008).

The *self-renewing* nature of sublation in metamodernism is also reflected in geographical research into historical and cultural spatial processes. Colonial and postcolonial geographies are no longer read solely as narratives of European expansion (the modernist narrative) or purely as deconstructions of Western influence (the postmodernist narrative). Instead, they are interpreted as dynamic interactions between local and global forces, resulting in continuous hybridization and redefinition of cultural and economic relations.

Similarly, the evolution of geopolitical thought is no longer viewed as a linear progression from realism to liberalism and postmodernism but as an ongoing reassessment of geopolitical theories within new historical contexts. Old principles

transform through oscillation into new syntheses. In the global epoch, the boundaries between local and global have become increasingly blurred. Processes of globalization and localization do not negate one another but mutually influence each other through *sublation*, often referred to as *glocalization*. For example, while multinational corporations like McDonald's or Subway standardize global production, they also adapt their products to local markets (such as offering vegetarian menus in India or ensures that its meat is halal-certified in the Middle East). Similarly, Starbucks offers green tea frappuccinos in Japan, Teriyaki chicken sandwiches in China, and dulce de leche lattes in Latin America; KFC serves spicy paneer zinger burgers in India and congee for breakfast in China; Domino's Pizza includes paneer tikka and keema do pyaza pizzas in South Asia, while offering corn and tuna toppings in South Korea. Even IKEA includes local dishes like biryani in its Indian outlets or kimchi fried rice in South Korea, reflecting how global brands embed themselves in local cultural and culinary contexts (e.g., Alamuri, Aluvala, 2024). In regional geography, sublation is manifested through ongoing dialogue between global trends and local realities, constantly transforming these into higher levels of understanding.

Metamodern geography is conceived as a continuous process of oscillation, transformation, and reinterpretation, wherein sublation does not eliminate previous paradigms but transforms them into higher levels of understanding and synthesis. Sublation thus emerges as an effective tool for addressing the challenge of inter-paradigmatic integration within geography. It enables flexible transcendence over binary conflicts between different approaches and fosters the creation of new syntheses that account for the complexity of geographic phenomena. Despite its strengths, this approach necessitates a high degree of reflexivity, epistemological discipline, and practical sensitivity to the limitations inherent in each paradigm.

In sum, the concept of sublation within metamodern geography allows for a more nuanced and adaptive framework for understanding and researching complex spatial phenomena. It promotes a vision of geography as a field in constant motion—integrating past paradigms while transforming them into new, higher-order syntheses. However, achieving such integration requires rigorous methodological reflection, a commitment to epistemological plurality, and a deep awareness of the contextual limitations inherent in every paradigm.

Oscillation of Scientific Discourses

One of the key principles of metamodernism, according to Pipere and Mārtinsone (2023), is simultaneity induced by oscillation. This principle describes how scientific discourses oscillate between two distinct models of scientific organization: the hierarchical model (represented by the metaphor of a tree or pyramid), typical of modernism, and the network model (represented by the metaphor of a rhizome—

an underground root system), characteristic of postmodernism. Neither approach is considered superior; rather, both coexist and influence each other depending on context and situation. This oscillatory principle allows scientists to integrate diverse approaches, oscillating between specialization, interdisciplinarity, and transdisciplinarity, enabling them to respond to the complex challenges of contemporary society. Oscillation, therefore, is seen as an inevitable and positive aspect of scientific development (Pipere & Mārtinsone, 2023, pp. 10-11).

In geographical research, two fundamental models of knowledge organization have been long applied. The hierarchical model, represented by modern positivist geography, examines the world through rigid spatial units (such as states, regions, and cities) and organizes scientific knowledge into disciplines and subdisciplines with clearly defined boundaries. Conversely, the rhizomatic model, typical of postmodern geography—such as relational geography and concepts like the "space of flows" (Castells, 1989)—understands landscapes and social structures as interconnected, dynamic nodes in constant interaction.

Metamodern geography does not prioritize either model but oscillates between them depending on the nature of the studied problem. For example, in the analysis of global megatrends (e.g., climate change, migration, urbanization), it becomes essential to establish connections between hierarchical levels (e.g., national policies) and rhizomatic networks (e.g., cross-border migration flows, digital spaces). Geography, as a transdisciplinary science, plays a pivotal role in linking academic research with societal needs. The principle of *metamodernist negotiation* (Pipere & Mārtinsone, 2023) manifests in two primary dimensions. First, in thematic areas such as environmental sustainability, climate change, or urban planning, scientific inquiry extends beyond academia to actively involve local communities, policymakers, and organizations in co-creating knowledge. A practical application of this principle is reflected in Responsible Research and Innovation (RRI) in geography (Owen et al., 2012). For instance, in the development of smart cities (e.g., Shayan, Kim Pyung 2023), it is crucial to negotiate between technological innovation and social impacts, addressing concerns like digital inclusion, gentrification, and urban ecological footprints. Critical cartography (e.g., Crampton, Krygier, 2005) also illustrates the metamodernist approach, emphasizing that maps are not neutral representations of reality but reflect specific value-laden and political frameworks.

The oscillatory principle further applies to defining geography's position within the scientific system. As previously discussed, geography is not a closed system with fixed boundaries but an open, flexible discipline that integrates knowledge across natural, social, technical, and humanistic sciences. This shift allows for better reflection on the complex relationships among environmental, political, economic, social, cultural, and technological processes—relationships that cannot be adequately captured within traditional disciplinary and subdisciplinary

frameworks. Post-disciplinary geography is thus characterized by permeability between methodological traditions and the capacity to integrate diverse analytical approaches based on the nature of the phenomenon under study. This approach enhances the discipline's ability to navigate the complexities of contemporary spatial, societal, and environmental processes. A notable implication of this oscillatory principle is the dissolution of any singular universal paradigm capable of addressing the full complexity of geographic phenomena. Unlike the modernist model, which favored a unified theoretical framework, and the postmodernist model, which critically deconstructed existing paradigms, metamodern geography embraces oscillation between multiple epistemologies and theoretical frameworks.

Thus, post-paradigmatic geography does not perceive methodological traditions as opposing but regards them as complementary tools for capturing complex realities (see Matlovič, 2007). Geography, therefore, oscillates between: the hierarchical model of science – where subdisciplines such as physical and human geography evolve within structured categories, and the network model of science – where interdisciplinary connections (e.g., between geography, anthropology, economics, sociology, political science, spatial planning, environmental science, development studies, risk management, information science) continuously change and adapt according to current research needs. This oscillatory approach equips geography with greater adaptability to the dynamics of the contemporary world, where rigid disciplinary boundaries and paradigmatic rigidity hinder understanding of interwoven spatial, social, and environmental processes.

Navigating Paradoxes: Truth and Grand Narratives in Metamodern Geography

Another metamodernist principle is the paradoxical position of truth and grand narratives in contemporary science (Pipere, Mārtinsone 2023). The authors highlight the ambiguity of truth in modern science, which oscillates between objective and subjective understandings. Objective truth has traditionally been regarded as universal and fixed. It was prioritized during the era of modernism, where scientific progress and truth were key values. Subjective truth reflects the relativity and contextualization of scientific knowledge, characteristic of postmodernism. The authors argue that in metamodernism, truth is understood as the simultaneous interplay of objective and subjective perspectives, with both approaches having their place in different scientific fields and discourses. This approach allows scientists to oscillate between relative and absolute understandings of truth, depending on the context and area of research (Pipere, Mārtinsone 2023, 11-12).

The authors claim that grand narratives return in metamodernism but in new forms. These are no longer universal "truths," but pragmatic, dynamic, and situated metanarratives that oscillate between different discourses. They provide examples

of these contemporary metanarratives: sustainability (connecting science with societal challenges related to the environment), the search for meaning (where science engages in broader discussions on how to improve human life and society), and digitalization (where science helps manage the transition to a digital society, with digitalization itself being perceived as a new grand narrative) (Pipere, Mārtinsone 2023, 11-12).

In geographical thought, the principle of the paradoxical position of truth and grand narratives can be applied to the reconceptualization of traditional concepts such as space, place, and region, which oscillate between objective and subjective approaches. Traditional geographical analyses, based on quantitative methods, mapping, and spatial relationships, reflect the modernist ideal of universal, objective truth, wherein space is perceived as measurable, structured, and predictable. Conversely, postmodern geography emphasized the subjectivity of spatial perception, focusing on the social construction of space and the plurality of meanings that individuals and communities attribute to places (Matlovič, Matlovičová 2007).

A metamodernist approach in geography integrates these perspectives, conceptualizing truth not as fixed and immutable but as a dynamic process in which scientific knowledge oscillates between precise models and interpretative narratives. For instance, the concept of quality of life can be both objectively quantifiable and subjectively experienced (e.g., Ira, Andraško, 2007, Petrovič, Murgaš, 2020).

The culmination of this oscillation is the return of grand geographical narratives in a new form: globalization, climate change, and digitalization are currently regarded as macro-processes with objectively measurable impacts, while their interpretation is shaped by cultural, political, and social contexts. Geography, consistent with metamodernist logic, does not reject grand narratives but approaches them with flexibility—examining their significance and applicability in specific contexts. This contributes to the formation of pragmatic and dynamic metanarratives that reflect contemporary challenges.

Beyond Boundaries: Embracing Dia/Polylogical Thinking in Metamodern Inquiry

The next principle of metamodernism emphasizes the dynamic oscillation between various perspectives, disciplines, and levels of knowledge, with the key concept being dia/polylogical thinking (Pipere, Mārtinsone 2023). This principle encompasses multiple layers: scientific thinking, the system of science and interdisciplinary interaction, the dialogue between science and society, and the concept of open science. The authors highlight the inherent complexity of scientific thinking, which often leads to the production of so-called demi-reality—

false beliefs and implicit assumptions that may arise from excessive analysis or abstraction devoid of context.

The authors advocate for metaxis-based thinking, characterized by the ability of scientists to oscillate between different approaches and perspectives rather than rigidly adhering to a single position. This involves transcending boundaries between scientific disciplines and oscillating between monodisciplinary, interdisciplinary, and transdisciplinary approaches. However, it is not limited to the oscillation between knowledge or methods but emphasizes active engagement in dialogue (polylogue) among scientists, society, policymakers, citizens, and other stakeholders. In this context, polylogue is understood as a multidimensional process that highlights the plurality of perspectives, collaboration, and the continuous enrichment of science with new insights and experiences, which are essential for addressing contemporary global challenges. Polylogue is not merely an exchange of information but a process of collective learning and reflection, where participants mutually enrich their knowledge and experiences. Open science and digitalization represent practical applications of this principle in the 21st century. Science becomes more accessible and democratic, engaging diverse actors in the creation, dissemination, and utilization of knowledge (Pipere, Mārtinsone 2023, 12-17).

In geographical thought, the principle of dia/polylogical thinking can be applied to the exploration of relationships across different scales (local, regional, global), between diverse methodological traditions (quantitative vs. qualitative geography), and between academic research and public discourse on space and society. This principle promotes transdisciplinary thinking in geography, oscillating between monodisciplinary, interdisciplinary, and transdisciplinary approaches.

For instance, in the analysis of climate change, geography integrates knowledge from physical geography (changes in atmospheric circulation, topography, and vegetation) and human geography (social consequences, environmental justice, adaptive strategies of populations) while actively engaging in polylogue with climatologists, sociologists, economists, ecologists, and policymakers to develop holistic frameworks for addressing environmental challenges (e.g., Fu et al. 2025). A practical application of this principle is open science in geography (e.g., Singleton et al. 2016), where digitalization, participatory mapping, and crowdsourcing are utilized to involve the wider public in the production of geographical knowledge. For example, the concept of "citizen science" enables citizens to participate in the collection and analysis of geographic data (e.g., OpenStreetMap, environmental monitoring applications), thereby expanding the framework of scientific inquiry beyond traditional academic institutions. Polylogue in geography is also evident in addressing issues such as the exploitation of natural resources, land-use changes, the development of social awareness regarding environmental threats, and the sustainable development of rural areas—where diverse perspectives intersect,

including those of environmental movements, development planners, and local communities (e.g., Wójcik, Dmochowska-Dudek, 2024). In such cases, geographical thought does not offer unilateral solutions but creates space for oscillation between competing narratives, facilitating participatory planning and negotiation among stakeholders (e.g., Cilliers, Timmermans 2014).

Overall, metaxic thinking in geography fosters the integration of diverse epistemologies, disciplines, and perspectives, enabling oscillation between theoretical models and empirical realities, between scientific expertise and local knowledge, and between academic research and public engagement.

Spatial Dialogues: Coexisting Cultural Stages in Global and Local Contexts

The principle of the coexistence of cultural evolutionary stages within the metamodernist framework, connected to Storm's concept of metarealism, emphasizes the simultaneous existence of various cultural stages in contemporary science and their integration into a complex scientific discourse. Metarealism, as a fundamental philosophical pillar of metamodernism (Storm, 2021), provides a framework for understanding reality as a multilayered and oscillating phenomenon, where each cultural stage represents a specific "mode of reality." These modes are not rigidly separated but coexist and mutually influence one another depending on context and historical circumstances.

Pipere and Mārtinsone (2023) describe metamodernism as a transversal principle that connects and utilizes elements from all previous cultural epochs, including tribal life, polytheism, traditional theology, modern industrialism, and postmodernist critique. In metamodernism, various cultural paradigms exist side by side like "parallel universes." These paradigms are not necessarily in conflict but may complement one another, allowing scientists to draw wisdom from past epochs while avoiding narrow and one-dimensional approaches. This coexistence is not merely theoretical; it is manifested in scientific disciplines and fields that integrate traditional knowledge with modern and postmodern approaches.

The authors suggest that the principle of coexistence can be best illustrated through the concept of post-normal science. This concept is derived from Thomas Kuhn's notion of "normal science" but focuses on complex and uncertain problems that cannot be solved by simple systems. It emphasizes managing problems characterized by high risk, uncertainty, and multiple legitimate perspectives. The coexistence of different stages of cultural evolution is closely linked to the preceding principles of metamodernism (Pipere, Mārtinsone 2023, pp. 19-20).

Geography today already analyzes how various forms of spatial organization of society intersect within a single global reality, ranging from traditional tribal structures to the digital global network. For example, in cities of the Global South (such as in India, Nigeria, or Brazil), one can observe the concurrent existence of traditional neighborhoods characterized by spontaneous urbanism, industrial

production zones, and post-industrial smart cities (e.g., Rajendran et al. 2024). Metamodern geography does not evaluate these models through a hierarchical scheme of progress but rather examines how they influence and co-shape each other.

In rural geography, the coexistence of traditional agricultural forms (e.g., ecological farming, pastoralism) with hyper-technological agro-industrial processes (e.g., vertical farming, the use of AI in agronomy) can be observed (e.g., Colombo, Onorati, 2013). The coexistence of different cultural stages is also reflected in theoretical geographical thought, where various philosophical and methodological frameworks intersect and mutually influence one another. For instance, the geography of natural hazards combines traditional knowledge of indigenous communities about natural disasters (such as predictive signs of tsunamis in Polynesian culture) with modern geoinformation systems (e.g., GIS modeling of risk areas) (e.g., Hemi et al. 2024).

Metamodernism does not reject grand narratives but perceives them as dynamic, open, and contextual. One such contemporary grand narrative is digital transformation and cyberspace, which fundamentally reshapes geographical thought. Metamodern geography, therefore, explores how historical forms of spatial organization (e.g., agrarian settlements, industrial metropolises) intersect with new forms of digital and global hyperconnectivity.

The principle of the coexistence of cultural stages in metamodernism offers geography a transversal approach that integrates historical, contemporary, and future perspectives into a complex, multilayered understanding of the world.

GEOGRAPHY IN OSCILLATION: A METAMODERNIST RECONCEPTUALIZATION

Based on the preceding reflections, we can approach the metamodernist reconceptualization of geography as a scientific discipline. As the foundation for this reinterpretation, we will utilize the definition of geography formulated in one of our previous works (Matlovič, Matlovičová 2015, 8-9).

Within the metamodernist framework, geography is characterized as an oscillating discipline that avoids rigid dichotomies and transcends individual paradigmatic frameworks. It is ontologically fluid and metarealistically grounded, reflecting the multilayered nature of reality where natural, social, technological, and cultural dimensions coexist in constant interaction. Drawing upon a hylosemiotic understanding of space, geography perceives the Earth's landscape sphere as a dynamic sign system, where materiality and meaning continuously transform and influence one another.

Ontologically, geography operates within the space of *metaxy*—between stability and change, between the material and immaterial—while reflecting the relationships between the physiosphere, biosphere, sociosphere, technosphere,

noosphere, and cybersphere. These spheres are not separate but interconnected within the Earth's landscape sphere as zones of intense interaction along a global-local continuum. Within this space, dynamic oscillation occurs between various modes of reality, as formulated by metarealism. Geography, therefore, examines phenomena that are both materially grounded and socially constructed.

Epistemologically, geography is pluralistic and zetetic, meaning it acknowledges the limits of knowledge while promoting abductive and flexible approaches that enable progressive and practically oriented understanding of the world. This implies that geographical knowledge is continually open to revision, oscillating between skeptical questioning and the practical search for the best explanations. Geography seeks to identify and analyze complex connections between spatial, social, and environmental processes.

Methodologically, geography employs three hylosemiotically interconnected research perspectives:

a) Compositional Perspective - this perspective reflects the examination of geodiversity as a dynamic interaction between signs and material structures. Space is understood as a hylosemiotic structure, where physical, technical, social, ideological, and digital components intersect, creating a complex network of meanings. Research focuses on identifying the signs that stabilize spatial formations and understanding their variability within spatiotemporal structures.
b) Socio-Constructivist and Contextual Perspective - this perspective concentrates on analyzing semiotic networks, in which places are defined not only by their physical location but also by meaningful and relational interactions. Geography investigates how signs, practices, and discourses shape socio-spatial processes, how actor networks develop, and how the meaning of places transforms within global-local dynamics.
c) Substantial-Axiological Perspective - this approach explores how communities perceive and interpret their environment, how they attribute meanings to material and immaterial elements, and how these meanings shape their identity, values, and everyday efforts. Meanings are not merely subjective projections but are materially grounded in the environment and co-create the semiotic landscape of a place.

Geography, in the metamodernist spirit, is thus post-disciplinary, post-paradigmatic, and transversal, emphasizing the interconnectedness and mutual oscillation of various spheres and epistemological approaches. It is a science that not only reflects reality but also participates in its transformation towards *multispecies flourishing*—the joint thriving of humans, nature, and technologies—thereby demonstrating its social relevance (see Matlovič, Matlovičová 2012) in its heuristic, applicative, educational, and moral dimensions.

GEOGRAPHICAL THOUGHT IN FLUX: NEGOTIATING MODERN, POSTMODERN, AND METAMODERN PERSPECTIVES

The relational constellation between modern, postmodern, and metamodern geography is currently complex and multilayered, manifesting elements of conflict, tension, but also complementarity and synthesis. This constellation can be most accurately characterized as an oscillating symbiosis with elements of selective synthesis. Historically, modernist and postmodernist geography have been positioned in an antagonistic relationship. Modernism advocated for universal truths, objectivity, and systematic approaches, whereas postmodernism challenged these approaches, emphasizing plurality, subjectivity, and the relativity of knowledge. Their epistemological foundations were often in direct conflict, leading to tensions in scientific debates.

Metamodernism also grapples with tensions towards previous paradigms, particularly in its critique of postmodern skepticism, which it considers restrictive. At the same time, some modernist traditions criticize metamodernism for excessive theoretical abstraction and a limited practical application to date. However, metamodern geography does not seek to entirely reject previous paradigms but rather to integrate and synthesize them (see Table 1). Metamodernism perceives the development of geography as a process of oscillation and mutual complementation. From modernism, it adopts an emphasis on systematic approaches, empiricism, and the pursuit of identifying universal patterns. From postmodernism, it embraces sensitivity to subjectivity, plurality, and the contextuality of knowledge.

This sublative (synthesizing) approach means that metamodernism seeks to overcome the antagonism between modernism and postmodernism, recognizing the value of both directions and utilizing them according to different contexts. Metamodern geography approaches conflicts between previous paradigms dialectically and dynamically. It understands their interaction as a continuous oscillation between opposites, leading to productive tension and mutual enrichment. This approach enables complementarity: where modernist approaches offer precision and universality, postmodern perspectives contribute context and subjective experience.

Metamodernism oscillates between these poles based on the needs of specific research and issues, providing a flexible and context-sensitive framework for addressing contemporary geographical challenges.

Table 1 Simplified comparison of the fundamental attributes of modern, postmodern, and metamodern geography

ATTRIBUTES	MODERN GEOGRAPHY	POSTMODERN GEOGRAPHY	METAMODERN GEOGRAPHY
Philosophy	Empiricism, rationalism, positivism, logical positivism, critical rationalism, structuralism	Social constructivism, post-structuralism	Metarealism
Truth	Objective, universal, and measurable. Assumes the existence of a single reality that can be precisely known through scientific methods and empirical evidence.	Contextual, subjective, and socially constructed—resulting from discourse, language games, and social interactions, acknowledging a plurality of truths and interpretations.	Processual, oscillating, and contextually grounded. Respects the plurality of perspectives while seeking practical, best explanations, recognizing that certainty is always temporary and open to revision.
Ontology	Based on realism and essentialism. Assumes the existence of an objective and independent reality that exists regardless of human perception and exploration.	Prefers anti-realism and perceives reality as a result of social constructions. Rejects essentialism and emphasizes the social construction of narratives and power structures.	Oscillates ontologically between realism and constructivism, emphasizing the dynamic and relational nature of reality. Balances essentialism and constructivism, perceiving them as complementary rather than antagonistic approaches.
Epistemology	Prefers positivist epistemology—emphasizing scientific objectivity, universal laws, and causal explanations.	Prefers epistemological relativism, emphasizing subjective perception, the contextual nature of knowledge, and the examination of power structures within scientific discourses.	Emphasizes plurality of approaches, flexibility, and continuous reflection. Oscillates between objectivism and relativism, leaning towards zetetic epistemology. Acknowledges uncertainty in knowledge while emphasizing productive and practically oriented research of reality.

ATTRIBUTES	MODERN GEOGRAPHY	POSTMODERN GEOGRAPHY	METAMODERN GEOGRAPHY
Methodology	Emphasizes empirical-analytical, deductive, and quantitative methodological approaches. Utilizes systematic mapping, statistical analysis, and modeling to identify universal laws and rules determining geographical phenomena.	Emphasizes qualitative, hermeneutic, critical, and interpretative approaches, reflecting the plurality of perspectives and subjective experiences. Focuses on analyzing discourses, social constructions, and meanings attributed to spatial entities by actors.	Advocates for post-paradigmatic openness, allowing for the combination of various research frameworks to achieve a comprehensive understanding of the studied problem. Oscillates between quantitative and qualitative approaches depending on the nature of the studied phenomenon. Prefers abductive and reflexive methodological strategies, enabling continuous revision of knowledge and openness to the complexity of studied phenomena.
Paradigms	Prefers paradigmatic stability, favoring unified and firmly grounded scientific paradigms based on positivist and empirical approaches.	Rejects a unified paradigmatic structure, emphasizing plurality, fragmentation, and skepticism towards grand theories. Accepts multiple equally valid paradigmatic approaches reflecting the contextual and subjective nature of knowledge.	Does not reject paradigms but perceives them as flexible and temporary constructs adaptable to the complexity of studied phenomena. Employs the concept of metaxic oscillation, allowing scientists to move between different theoretical approaches and integrate them for a deeper understanding of spatial phenomena.

Source: Own elaboration based on Matlovič, Matlovičová 2015

LIMITS AND RISKS OF METAMODERNISM'S RECEPTION IN GEOGRAPHICAL THOUGHT

In the context of adopting the metamodernist framework in geographical thought, it is essential to critically examine several issues concerning its practical applicability and conceptual coherence. Although metamodernism offers an intriguing theoretical perspective, there are several significant limitations and risks that must be addressed to ensure its meaningful integration into geographical research.

As geographical thought increasingly engages with the metamodernist paradigm, it becomes essential not to approach this engagement uncritically, but rather through a spirit of zetetic inquiry—that is, a searching attitude that oscillates between skepticism and constructive affirmation. The adoption of metamodernism is not without friction, and its integration into geography must reckon with its conceptual fluidity, methodological ambiguity, and the demands of empirical accountability.

Metamodernism invites geography into a liminal space—*metaxy*—where tradition and innovation, objectivity and subjectivity, theory and praxis co-exist in dynamic tension. Yet, one of the pivotal challenges lies in grounding this liminality within concrete research practices. While the conceptual apparatus of metamodernism—such as oscillation, metarealism, zetetism, and hylosemiotics—offers a richly textured reimagining of the geographical imagination, it remains, at present, primarily a theoretical framework. Its contribution to solving specific geographic problems or generating novel empirical insights is still emergent, and often speculative.

Translating metamodernist insights into operational research strategies remains a formidable task. The emphasis on oscillation across epistemological and methodological boundaries demands more than rhetorical flourish; it requires a refined methodological architecture that can accommodate fluidity without losing coherence. In the absence of structured guidance on how oscillatory thinking should be enacted in research design, data interpretation, or analytical synthesis, there is a risk that researchers may drift into interpretative ambiguity or methodological eclecticism that compromises analytical rigor. Constant negotiation between different approaches can blur the boundaries between validated scientific knowledge and speculative constructions.

Moreover, while metamodernism aspires to move beyond the paralyzing relativism of postmodernism, its commitment to embracing contradiction and pluralism might inadvertently reproduce some of the same uncertainties. The constant interplay between divergent paradigms, while philosophically enriching, must not undermine the pursuit of empirical clarity and methodological integrity. The danger lies not in the oscillation itself, but in failing to differentiate between

generative hybridity and incoherent synthesis. If left unchecked, the drive for inclusivity may dilute the epistemic precision geography relies on to inform spatial governance, environmental and spatial planning, or socio-ecological resilience.

Thus, the task before geographical scholarship is not to abandon metamodernism due to its current indeterminacies, but to refine it through iterative praxis. It must demonstrate its epistemological robustness not through totalizing claims, but through situated applications that show how its concepts generate insight within real-world spatial contexts. Metamodern geography, to fulfill its promise, must balance poetic ambiguity with analytic discipline—keeping one foot in theory's open horizon and the other grounded in empirical terrain.

In sum, metamodernism should be welcomed not as a ready-made solution, but as an open framework for rethinking geography's methodological futures. Its success will depend not on discarding precision for pluralism, but on reimagining precision itself as a relational, adaptive, and ethically attentive practice. Without evidence that metamodernist principles can enhance geographical analyses or contribute to applied research—such as in urban and territorial planning, environmental policy, spatial justice, disaster risk management, smart territorial development, climate change, migration, polycrisis, or the reinterpretation of place-based identities in digital geographies—its practical relevance remains an open question.

CONCLUSION

The metamodern shift in geographical thought represents a potential response to the complex challenges of the Anthropocene polycrisis, encompassing environmental, geopolitical, social, economic, and technological transformations. This shift reflects the need for new epistemological and ontological approaches capable of better explaining and addressing the complex and multifaceted problems of the present. At the core of metamodernist thinking lies the concept of oscillation between opposites, manifested in efforts to transcend the rigid dichotomies of modernism and postmodernism. This concept introduces a new approach to understanding space, place, and geographic processes as dynamic and multilayered realities. Geographic objects are not viewed solely as fixed and objective entities but also as social and cultural constructs that oscillate among various interpretations and values.

The key concepts of metamodern geography include metarealism, zetetism, hylosemiotics, sublation, the oscillation of scientific discourses, and the coexistence of layers of cultural evolution. Metarealism contributes to defining geography as a discipline that reflects the complex and layered realities of the Earth's landscape sphere, where material, social, and ideological elements mutually influence one another. Zetetism promotes a critical and practical approach to knowledge, where

the search for the best possible explanations is regarded as a continuous process open to revision. Hylosemiotics offers a new perspective on the relationship between material structures and meanings, enabling a better understanding of the complex nature of space and place. Sublation represents the process of transforming and integrating opposites, contributing to the creation of new syntheses and understandings. The oscillation of scientific discourses highlights the need for a flexible and pluralistic approach in geographical research that integrates various methodologies and perspectives. The coexistence of layers of cultural evolution emphasizes the importance of drawing from the knowledge and experiences of various cultural eras, enhancing geography's capacity to respond to contemporary global challenges.

Unlike modern geography, which prioritizes empirical universality, and postmodern geography, which focuses on deconstruction, metamodern geography actively oscillates between structured analysis and reflexive engagement. This enables it to integrate rational-empirical insights with qualitative humanistic perspectives, creating a more adaptive and context-sensitive approach to spatial research. Thus, metamodern geography is shaped as a post-disciplinary, post-paradigmatic, and reflexive science that avoids rigid categorizations and embraces the integration of various disciplines, methods, and perspectives. It allows for a deeper understanding of the complex relationships between humans, society, and the environment in a dynamic and ever-changing world.

Although metamodernism offers intriguing ideas for geographical thought, its practical applicability and conceptual robustness remain open questions. For its further development, it will be essential for metamodernist concepts to demonstrate their empirical utility, offer practical methodological frameworks, and avoid the risk of abstract theorizing that could disqualify them from the realm of practical scientific research.

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ARTIFICIAL INTELLIGENCE AND TOURISM IN THE EU: A DATA-DRIVEN ANALYSIS OF ADOPTION AND ECONOMIC CONTRIBUTION

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Abstract
Tourism is continually shaped by emerging technological innovations. Artificial intelligence (AI) is also rapidly transforming the travel industry by enhancing operational efficiency, optimizing cost management and improving the customer experience. With the help of AI, experience is personalized, accommodation services are automated, and consumer decision-making is assisted. This paper deals with the role of AI in the tourism of EU countries, its benefits and future expectations of the global market. The data base consisted of the global AI index, its dimensions, the share of GDP for tourism in the total GDP for 2019. We rely on the analysis of the main components as the basis of our chosen methodology. This method is recognized for data visualization, helping to reveal correlations between quantitative variables. We also applied cluster analysis and biplot visualization to identify interrelationships and patterns in the data set. The main goal of the paper is to provide a more comprehensive overview of the latest AI solutions and their application in tourism. In our analysis, we evaluate important AI innovations that will continue to shape the future of tourism, such as virtual assistants, chatbots, predictive assessments or biometric technologies. We also analyze the uniformity in the use of AI in a set of EU countries in the context of the share of tourism in GDP creation. The presented paper highlights potential future trends that are likely to play a significant role in sustainable and intelligent travel. The role of AI in tourism is substantial and is expected to expand as countries want to use customer experiences and optimize their business strategies and operations based on them. Our results demonstrate the uneven distribution of AI development in tourism across EU countries. We identified differences depending on infrastructure, talent, commercial integration and applied public policy. Based on the previous review of AI applications in tourism, we suggest specific AI steps that similar countries in each cluster should take to increase the importance of tourism in their economies through the effective use of AI technologies.

Key words
Tourism, artificial intelligence, business, customer, sustainability.

INTRODUCTION

Tourism sector is influenced and shaped by new technologies like never before. Easy and comfortable access to new tools such as chatbots, virtual assistants, online reservations, virtual tours, personalized recommendations or digitization are reshaping customer behavior. Today, tourism is no longer only about physical travel, but thanks to rapidly advancing technologies, it is also about data-driven experiences. They primarily bring significant flexibility to customers, access to the entire spectrum of information and also comfort. These transformational changes give rise to new business models and services that reflect the dynamics of the current era and the rapidly changing expectations of travellers. Artificial intelligence (AI) has become a significant driving force in this context, driving innovation and transformation. AI tools help not only to process and evaluate a large set of data quickly, but also effectively, which allows tourism actors to predict possible trends in further development, and also predict customer behavior. There is also an increase in the level of personalization, which is a key aspect to maintain and increase traveler satisfaction. AI can be an important help for travel agencies, accommodation facilities, transport companies in the light of adapting the offer to the individual needs and preferences of customers. These are then reflected in visiting and formulating recommendations for specific destinations, improving communication in real time or customizing the itinerary. AI as a technological breakthrough, helps automate many processes, ranging from chatbots to predictive equipment maintenance or capacity management. The increased demand needs to be effectively managed, which is again a space for AI. This increases transparency and sustainability by optimizing the use of resources and eliminating the carbon footprint of travellers. In this paper, we focus on the role of AI in tourism and its benefits to the industry itself. Tourism is a highly innovative industry and must respond to the changing expectations and needs of the global market. We also dedicate space to possible future development directions related to the implementation of AI. These include cyber security, privacy or ethical issues related to automation.

As the consumer behavior models and consumer expectation are changing, the demand for innovative solutions is increasing. These can shape the way travellers have interacted with destinations so far. Technological solutions offer a more convenient choice, planning and experience of trips. Digitization in tourism brings such revolutionary tools as online reservations, virtual tours, personalized recommendations. Thanks to them, travellers have an opportunity to obtain a large amount of information that helps them in their decisions about the choice of services in the tourism industry. The position and role of artificial intelligence

tools in business and on a global scale is undeniable. Bughin et al. (2018) on behalf of the McKinsey Global Institute conducted research focused on the simulated impact of AI on the world economy. Special attention was paid in the research to the adoption of AI technologies. The results of their findings suggest that artificial intelligence tools have great potential to contribute to global economic activity.

However, they also reveal the risk of deepening disparities between individual regions and countries. Chui, M. et al. (2018) also, representing the McKinsey Global Institute, claim in their report that modern AI tools can be 128% more efficient in the tourism industry compared to conventional analytical methods. The research also focused on the evaluation of 18 other industries, but in the case of tourism it is the highest rate.

THEORETICAL FRAMEWORK

In addition to the fact that artificial intelligence transforms and innovates processes across the entire provision of services in the tourism industry, it has the ability to change or transform the potential and productivity of GDP at the level of the global economy. A prerequisite for meeting these goals of macroeconomic indicators are numerous investments in various types of artificial intelligence (PwC, 2017). Chi Software Company (2024) described the application of artificial intelligence in tourism as a revolution and explored the transformation of tourism by digital artificial intelligence through artificial intelligence applications. The findings are reported in their study and shown in Figure 1.

Figure 1 illustrates the potential added value of artificial intelligence compared to other analytical techniques. Axis X represents the percentage share of the impact of artificial intelligence on the total impact based on the analysis conducted. According to a McKinsey Company report, modern artificial intelligence analytical solutions are up to 128% more effective in the case of tourism compared to conventional analytical methods. This value is the highest among the other eighteen examined branches of the national economy. We note that the average value was found at the level of 62%. At the same time, the same research quantified the largest value generated by the application of artificial intelligence for tourism at the level of approximately 400 billion USD. It means a significantly higher contribution value compared to other areas. The quantified point for tourism is indicated by a pink dot directly in the graph. For entrepreneurs in the field of hospitality and tourism, artificial intelligence has a very inspiring effect and encourages the development and implementation of software solutions for the development of tourism, even for its significant decline in the previous pandemic period.

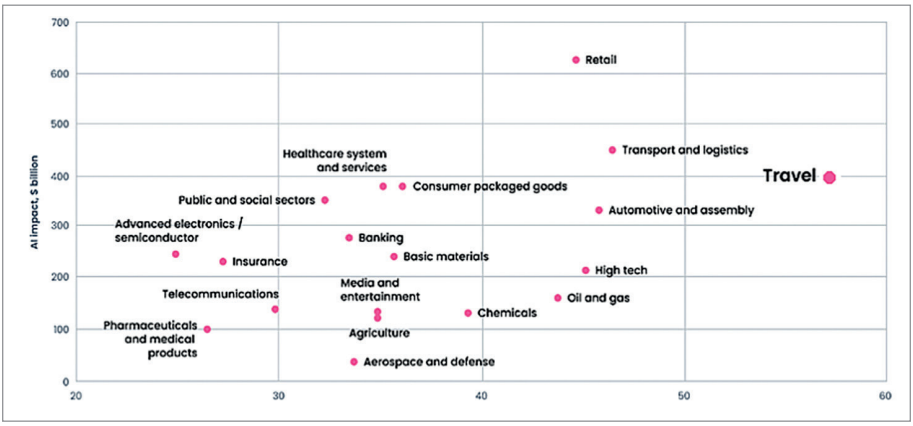

Fig. 1 Share of AI impact in total impact derived from analytics
Source: Shatalov (2024)

In their current paper, Collins, Ali and Yilmaz (2024) address the issue of artificial intelligence and its future implications for the tourism and hospitality sector. The authors bring an analytical view of advanced, deep artificial intelligence technologies and define up to seven technological solutions. Thanks to the advanced possibilities of information and communication technologies, it is possible to apply them in the future in order to get ahead of the competition, achieve a competitive advantage, reduce the business cost and reach new market segments.

Tab. 1 Possibilities of applying artificial intelligence in tourism

AI-BASED DL TECHNOLOGY (TYPE)	APPLICATION TO TOURISM
Convolutional Neural Networks CNN *An algorithm specifically designed for image processing and recognitions tasks* (Computer Vision)	Using CNN to recognize persons or prohibited objects at airports (secure registration at borders and check-ins), hotels and other tourist areas. It improves security controls and reduces the likelihood of risky situations. CNNs can analyze photos posted by tourists on platforms (e.g. TripAdvisor) and evaluate their emotional content (happy faces, satisfaction).
Style Transfer *A computer vision and graphics technique to combine the content of one image with the visual style of another* (Computer Vision, Graphics)	AI helps create personalized, dynamic and interactive experiences for tourists, increasing their satisfaction while improving the return on marketing investment.

AI-BASED DL TECHNOLOGY (TYPE)	APPLICATION TO TOURISM
Deep Learning Based Recomander system *An application that is based on multiple DL technologies, and uses an algorithm to suggest choises of interest on Big Data* (Ranking)	The concept of personalized itineraries involves the use of artificial intelligence (AI) to create tailor-made travel plans that consider travellers' preferences and needs. The concept of authenticated reviews uses AI to verify and ensure the authenticity of reviews about destinations, hotels, restaurants and other services in the tourism industry.
Generative Adversarial Network *A type of learning architecture that pits two neural networks against each other to generate new synthetic data in close resemblance to an existing data distribution* (Generative AI)	Personalized interactive adds - AI analyzes user data and advertising is adjusted based on user preferences. Tangibilization of future experiences - tourists can visualize and experience their planned experiences even before they take place.
Variational Autoencoder *An algorithm to generate new content while detecting and removing noise* (Generative AI)	Event simulations, accuracy in recreational programming - AI helps hotels plan activities such as wellness, sports programs or trips to match the profile of guests. AI can optimize recreational offers in cities (e.g. concerts, workshops, city tours) to attract more visitors.
Recurrent Neural Network *An algorithm that operates on sequential data to predict new outcomes.* (Sequential data processing)	Polylingual Tour - multilingual guide using AI allows tourists to receive information about destinations and attractions in their native language in real time. Universal Translations in tourism allow tourists to instantly and accurately translate signs, conversations or materials, increasing their comfort and independence while traveling. Accessible, Anti-Ableist Visitor Experiences - AI plays a key role in creating experiences that are inclusive for differently abled visitors, reducing barriers associated with disabilities or other barriers.

AI-BASED DL TECHNOLOGY (TYPE)	APPLICATION TO TOURISM
Graph Neural Networks (Solve problems related to graph-structured data)	Tourist Flow Prediction – AI is used to predict data to determine the number and behaviour of tourists in destinations. Tourist flow prediction is a powerful tool that enables effective planning, management and promotion in tourism with the help of AI. It makes it easier to cope with seasonal changes. It helps manage visitation in sensitive ecosystems and cultural sites to reduce negative environmental impact. Forecasts of the number of tourists allow more efficient planning of public transport, flights and other logistical elements. Forecasting the flow of tourists makes it possible to prepare for safety measures during major events or unforeseen situations such as natural disasters.

Source: processed and supplemented according to Collins, A., Ali, S.A., Yilmaz, S. (2024).

The author collective Collins, Ali and Yilmaz (2024) state that the means, possibilities and tools of artificial intelligence have literally invaded all spheres of the economy and are rapidly transforming the further development and direction of specific industries. Although artificial intelligence tools are quickly penetrating the tourism industry, this area is only poorly explored from a research perspective. The research study in question was undertaken to evaluate the application of artificial intelligence in hospitality and tourism. Among other things, the analysis revealed a new evaluation framework, through which there is a more effective perception of determinants affecting not only the acceptance, but also the integration of artificial intelligence tools in practice.

A slightly earlier published study by the scientific team of Huang et al. (2022) also dealt with the issue of deploying artificial intelligence in the field of tourism. The authors came to the conclusion that the inclination to accept means and tools of artificial intelligence in tourism and hospitality are differentiated in relation to the types of artificial intelligence. Chatbots, reservation systems, virtual agents, and search engines have a high tendency for acceptance and subsequent implementation. The application of artificial intelligence goes hand in hand with advancing innovations. The authors' empirical research confirms support for the continued implementation of various artificial intelligence technologies in hospitality services and in tourism as such.

In a short period of time, a number of scientific, professional and overview works dealing with the application of artificial intelligence have been published in scientific journals, scientific and conference proceedings, as well as in renowned

scientific databases. What still remains unexplored, which is and will have to be the subject of interest and research by experts, is the examination of the effectiveness of the functioning of the used applications and algorithms of artificial intelligence, as well as the variety of types of applications and multimodal data sets, note in their paper Doborjeh et al. (2022). The author team decided to evaluate the already implemented methods of artificial intelligence in hospitality services and tourism. They focused on choosing a destination, uncovering and evaluating patterns of consumer behaviour, and demand prediction possibilities. Deriving from these findings, they formulated topics for improving the quality of services provided to customers. Based on the performed analysis, the author's collective also formulates a proposal for the introduction of personalized modelling development through artificial intelligence as a platform for intelligent tourism.

A study, published by Pillai & Sivathanu (2020) explains how artificial intelligence and the integration of artificial intelligence technologies are influencing, transforming and will continue to reshape the tourism and hospitality industry in many dimensions. Their research highlights the potential challenges that entities operating in the tourism industry will have to deal with not only from a business perspective, but also from the point of view of regulatory authorities or customers. Miao & Yang (2023) recall the transformation of experiences from the perspective of tourism clients. Their paper conceptualizes the possible influence of artificial intelligence of the text-to-image type precisely on the sphere of experiences, starting with initial expectations, through perception and ending with memories of experiences.

The mentioned authors processed current trends in hospitality and tourism in international context, focusing on the integration and impact of artificial intelligence. However, the field of tourism does not avoid trends in the nearer, i.e. in Central European conditions for us. Several important strategic factors influencing the development of tourism also come to the fore. Pellešová and Vacha (2023), among others, reported on these trends and strategic factors in their earlier studies in this scientific periodical. Understanding current trends and the current position of tourism in interactional relationships also includes understanding culture, the interplay of semantic boundaries between the identity of a place, the image and reputation of a place (Matlovičová, 2024).

In recent years, sustainability has been significantly discussed on a daily basis in every sector of the economy, not excluding tourism. The international team of authors Khan, N. et al. (2024) focused their study on exploring the potential of deploying artificial intelligence methods and tools in the tourism industry, thus reflecting on the sustainability of business in this sector of the national economy. The implementation of artificial intelligence makes it possible to expand the effective way of managing resources and the entities themselves operating in the tourism industry. The strong development of technologies brings new

opportunities for deploying artificial intelligence in tourism operations as well. They have become more efficient and their activity more sustainable. Sustainability is manifested in these entities through development activities, more ecological operation, and environmental protection. The possibilities of deploying artificial intelligence are obvious, for example, in more efficient energy management, waste management, optimization of transport solutions and sustainable management of resources. All these steps lead to higher protection of the environment and better management of natural resources. The deployment of artificial intelligence also helps to facilitate and improve the provision of experiences, but with a higher degree of greening through the implementation of virtual assistants and recommended systems. Naturally, the development and deployment of artificial intelligence must also consider the aspect of personal data protection, privacy protection and other aspects of information security. The authors support the inclusive implementation of artificial intelligence and indicate possible challenges that will need to be faced mainly in developing areas.

The tools and means of artificial intelligence bring new opportunities, and today artificial intelligence itself represents a very effective tool for increasing efficiency in the tourism industry. Another group of researchers, Salameh Alkhazaleh et al (2024) highlight how artificial intelligence offers numerous innovative solutions applicable by various businesses within the tourism industry. According to them, it is possible to include, for example, intelligent systems used by travel agencies or companies providing transport services. This collective of authors states that thanks to artificial intelligence, the tourism industry is also undergoing a transformation. This creates new possibilities, development opportunities and also a change in consumer habits and interaction with individual destinations. The important question of how it is possible or appropriate to adapt to such a dynamic revolution of advanced technologies, when machines have already begun to achieve a higher level of intelligence than humans. In our view, this issue will encompass not only technological and social dimension but also philosophical and ethical challenges.

Modern solutions related to artificial intelligence can be attributed primarily to those with technical and natural science education, who were most responsible for the establishment and subsequent development of start-ups. The implementation of innovations and new solutions has introduced substantial resources, including financial investments to business entities, according to Filieri et al. (2021). Among the European start-ups, it is possible to mark the capital cities of important tourist destinations, which include Spain, France, the United Kingdom, as their pin. Artificial intelligence solutions primarily focus on processing large data sets, facilitating tasks such as data segmentation, automation of marketing activities, and similar activities.

In the context of the conclusions of the above-mentioned authors, a pair of foreign experts Doğan and Niyet (2024) state in their paper that thanks to the

possibilities of artificial intelligence, decisions based on large set of data become significantly more effective, which is manifested, for example, in the improvement and efficiency of the marketing strategies of tourism entities. They consider the most valuable fact to be the contribution of artificial intelligence in the ability to create personalized recommendations. Not only accommodation facilities, such as hotels, guesthouses, but also travel agencies and companies providing transport services help potential clients through chatbots in choosing or fulfilling their requirements. For example, at airports, modern facial recognition technology can immediately and accurately identify clients, which contributes to the smoothness and safety of operations. By collecting data on the client's previous travel history or preferences, artificial intelligence can propose customized destinations for the client, accompanied by catering and accommodation services. These conveniences will undoubtedly contribute to a higher level of travel experience. Tourism entities often encounter the problem of operational efficiency. This is another area where artificial intelligence can be utilized, as it is possible to optimize specific processes and service delivery.

Also Zhang et al. (2023) emphasize that chatbot is currently one of the most frequently used artificial intelligence tools in tourism services. It is a human-computer interaction. They consider the interest or willingness of customers to continue using chatbots to be an unexplored area. As part of their research, they developed an integrated model of factors that demonstrably influence customers' continued interest in using chatbots. Their research revealed a positive correlation in relation to expected performance, habits, personalization, social influence and anthropomorphism. Negative determinants according to research are the privacy and time risk. From a gender perspective, only two differences were detected, while no other distinction between men and women were observed.

Hsu et al. (2024) focused in their study on the possibilities of defining the benefits of artificial intelligence in the context of tourism development. Their approach represents a balanced concept defining the positive and negative sides of using artificial intelligence tools. According to their research, generative artificial intelligence can contribute to increasing business performance and enhancing the client's tourist experience. On the other hand, they consider the accuracy and quality of data to be a weakness of generative artificial intelligence. A collective of authors proposed a generative artificial intelligence concept with a special focus on tourism and multi-party datasets. Preliminary research points to the need to fine-tune the large language model through credible and specific documents. The new generative concept of artificial intelligence is capable of delivering timely, clear and accurate results based on the available data base.

The term artificial intelligence comes from computer science, but in a short time it has penetrated basically every sphere of life and science. This fact caused an increased interest in the academic and research spheres in monitoring the

penetration of artificial intelligence into individual spheres. The deployment of artificial intelligence brings new possibilities and new forms of solving a wide range of problems. This is also the case in the field of tourism. Kırtıl & Aşkun (2021) conducted bibliometric research on a sample of 102 scientific papers indexed in the world scientific database Scopus. Their bibliometric research activity was the first in the field of tourism and is still a suitable starting point for further research. Their activity led to the definition of key determinants. The high interest in researching artificial intelligence in the tourism industry results in high citation of such papers.

Another study of a wider range of experts by Kong et al. (2023) aimed to assess the current progress in artificial intelligence research, specifically within the fields of hospitality and tourism. Expert terms, trends in artificial intelligence research, keywords, content focus became the key content points. The study covered the period starting from 1991 with the identification of an increasing trend and a break in 2018. Since then, there has been a significant increase in interest and publications with the given issue. The collective of authors states that artificial intelligence has become the centre of interest of researchers and scientists. They also defined four thematic areas with the greatest degree of interest: the appearance of new technological solutions, the acceptance of technological innovation, the perception of tourism clients and the prediction of trends. While in the first period the interest was concentrating on the possibilities of artificial intelligence technologies, currently, according to the authors, the interest is focusing on the customer acceptance of artificial intelligence and their attitude towards it.

OBJECTIVES

The aim of this paper is to provide an overview of the use of artificial intelligence in tourism and its potential contribution to the sector. Based on the Global AI Index values and its individual dimensions, we will analyse the differences between countries and identify clusters of countries with similar characteristics. Based on the previous overview of AI applications in tourism, we will suggest specific AI steps that similar countries in each cluster should take to increase the importance of tourism in their economies through the effective use of AI technologies.

DATA AND METHODS

Methodical background of the issue was supposed to be based on current and appropriate methodological procedures. We followed the primary task, which was to evaluate the level of artificial intelligence. In order to be able to ensure an objective and compact analytical view of the investigated issue, it was necessary to apply a suitable metric recognized by the global professional community. In our case, we applied The Global AI Index by Tortoise Media (https://www.tortoisemedia.com/intelligence/global-ai/#data), which, following numerous

expert discussions across Europe and globally, has become well-established and is considered by experts as a suitable tool for quantification. The acceptance of this index for quantification is supported by the fact that it measures data for a sample of up to 83 countries that invest intensively in artificial intelligence. The evaluation is carried out on the basis of not only investments, but also innovations in constantly improving artificial intelligence technologies. The evaluation, using the global index of artificial intelligence is based on the evaluation and comparative evaluation of countries according to their ability to implement artificial intelligence, or the capacity to continuously innovate already existing artificial intelligence. The company Tortoise Media can be found behind the creation of the index, which constantly monitors the development of artificial intelligence on a global scale, both at the level of various countries and at the global level, and based on the collected data, develops professional expertise and analyses. It thus identifies key development factors. The composition of the index is based on the coexistence of several criteria used to quantify the country's capabilities in the field of artificial intelligence. In total, it can be stated that The Global AI Index is constructed using 122 indicators sourced from both public and private data. There were a total of 24 of these sources and 83 countries were involved. The input sources are made up of 3 supporting pillars (talent, research, government strategy), which are distributed into 7 supporting pillars.

The first pillar is implementation. Within this pillar we distinguish another 3 supporting pillars, which are talent, infrastructure and operating environment. The supporting pillar of talent integrates the availability of a qualified workforce capable of solving the issue of artificial intelligence. The second supporting pillar, which is infrastructure, focuses on the field of semiconductor production and also on the assessment of modern computer infrastructure in terms of its scope. The last supporting pillar in the first supporting pillar is represented by the operating environment, which deals with the regulatory context and monitors the level of public opinion about artificial intelligence. Innovation is defined as the second main pillar, which is formed by two supporting pillars: research and development. Research focuses on quantifying the quality and also the availability of volume not only of academic research, but also of research in industry. Development explores the possibilities of applying the availability of artificial intelligence technologies in various fields, including patents, and also explores the creation of new artificial intelligence models.

The last main pillar is investment. It is divided into two supporting pillars, which are Government Strategy and Commercial. The first supporting pillar quantifies the amount of government commitments in the area of artificial intelligence, including the amount of funds spent on fulfilling these commitments and implementing the national strategy in the area of investments in artificial intelligence. Commercial tracks start-up business entities and quantifies the level of their activity, monitors

and quantifies the level of commercial initiatives and the volume of private investments in the field of artificial intelligence. A good feature of the global AI index is the fact that it includes not only the core factors, but also additional components such as scientific publications related to artificial intelligence, the volume of patents, investments made in artificial intelligence, and also in the educational system focused on the field of artificial intelligence. The above helps to understand where the development of artificial intelligence is currently heading.

This paper is addressing the tourism industry and applies the indicator Tourism direct GDP as a proportion of total GDP, which is expressed in relative terms and was published by the World Tourism Organization (UNWTO) for the year 2019 (acronym Y2019). The goal of UNWTO is to provide a helping hand to member countries in the field of statistics, research and also technical assistance with a focus on activating initiatives aimed at improving the contribution of tourism.

Currently, as of the end of October 2024, data for only three countries - Greece, the Netherlands and Portugal – are available for the evaluated period of 2022. The UNWTO points out that the overall data is an estimate provided by the organisation. For the stated reason, we methodologically considered it objectively to use data from 2019 for evaluation purposes, because in this period the data were not affected by the impact of the pandemic. In the case of the two selected countries, which are Bulgaria and Cyprus, however, the data cannot be determined, as it is unavailable. In order to clarify our methodological procedure, we consider it necessary to state the reasons for the application of the global index of artificial intelligence for the year 2024 (or for the year 2023) and the share of tourism in the creation of the gross domestic product for the year 2019.

We have chosen the share of tourism in GDP for 2019 as a benchmark for several reasons. First of all, 2019 represents the last year before the outbreak of the COVID-19 pandemic, which had a significant impact on global tourism. Pandemic constraints such as lockdowns, travel restrictions, and reduced travel demand have fundamentally disrupted the normal functioning of the sector and caused sharp declines in tourism revenues.

Although tourism has gradually recovered in recent years, it still shows lingering effects of the pandemic, which could distort the results of the analysis. By using data from 2019, we get a more relevant picture of the importance of tourism in the economies of each country under normal conditions, without the temporary effects of the crisis situation. This approach allows a more precise evaluation of the long-term relationships between the level of AI development and the importance of tourism in national economies.

This algorithm or the combination allows us to include not only the latest but also stable data on artificial intelligence in our analyses. This subsequently leads to more accurate results of the performed analysis without the distorting influence of the pandemic situation.

An important method used in our evaluation is PCA Principal Component Analysis, which according to several experts (Blighe, K., Lun, A., 2021; Kassambara, A., 2017) serves not only to summarize, but also to visualize the information obtained for a set of data, which were observed and their description is possible based on the identified correlations between quantitative variables. We perform the quantification of information from the dataset through total variance. PCA principal component analysis has the advantage, among other things, that it can reduce the breadth of multivariate data to a small number of principal components, for example two or three. These can then be visualized graphically. In our case, we will use a biplot for graphic visualization. We consider the biplot suitable not only for the presentation of observations, but also for the presentation of variable matrices of multidimensional data in the same graph. This makes the visualisation more compact and comprehensive.

Hierarchical cluster analysis was applied, enabling the identification of mutual relationships and patterns within the collected data set. In cluster analysis, we use Euclidean distance to measure the similarity or dissimilarity between objects in a multidimensional space. Performing cluster analysis requires evaluation and assessment of the quality of the clustering results. Cluster validation is the process of evaluating the quality and stability of clusters obtained by cluster analysis. It involves various methods to verify that the identified clusters are well separated, homogeneous and interpretable. The selection of the clustering method can be done by using the agglomeration coefficient. Higher values of the coefficient are attributed to better clustering method.

Internal clustering validation evaluates the quality of clusters based on internal cohesion and separation. We used Dunn's index, which compares the smallest distance between clusters with the largest distance between points within a cluster. If the data set contains compact and well-separated clusters, the diameter of the clusters is expected to be small and the distance between the clusters is expected to be large. Thus, Dunn index should be maximized (Kassambara, 2017).

The stability of the clusters is necessary to trust the results of hierarchical clustering. Bootstrap validation provides an objective way to verify whether clusters are robust or may be the result of random fluctuations in the data. We used the pvclust package to validate the robustness of hierarchical clustering using bootstrap resampling. We compute the approximately unbiased (AU) probability values (p-values) by multiscale bootstrap resampling (Kassambara, 2017). The p-values are reported as percentages. Clusters with AU greater than 95% are very stable clusters, likely representing real patterns in the data. Clusters with AU between 90 and 95% are relatively stable, but may change with different sampling. Clusters with AU less than 90% are uncertain clusters, they may be artifacts or random clusters. If many nodes in the dendrogram have low AU p-values (<90%), the clustering is not very reliable and should be re-evaluated.

The analytical calculations performed by us were carried out in the R programming environment, which allows not only scientific calculations, but also the subsequent visualization of data through suitable software tools.

RESULTS AND DISCUSSION

The decisive part of the presented article is the results part connected with the discussion, which contains the essential findings based on the performed analysis. As a first step, we present the results of the descriptive statistics calculations, which are presented in Table 2 below.

Tab. 2 Descriptive statistics

ACRONYM	AVERAGE	MEDIAN	MINIMUM	MAXIMUM	STANDARD DEVIATION
Overall	13.8	13.0	5.0	28.0	5.7
Talent	13.3	11.0	5.0	35.0	7.3
Infrastructure	24.0	22.0	16.0	40.0	6.1
OperEnviro	66.4	67.0	27.0	100.0	15.3
Research	6.0	5.0	1.0	18.0	4.2
Development	6.3	5.0	0.0	31.0	6.9
GoverStrat	31.0	31.0	0.0	66.0	18.0
Commercial	8.6	7.0	1.0	19.0	5.0
Y2019	4.5	4.0	1.2	11.8	2.3

Source: own processing using software

Table 2 presents average values for various individual indicators. It is clear that OperEnviro with 66.4 points achieves the highest value, which indicates a favorable operating environment. Two categories with a small difference, which show the lowest values, were placed on the exact opposite pole. They are Research (with a score of 6.0) and Development (with a score of 6.3). The results signal weaker performance in the field of research and development. Regarding the assessment of other values, it can be emphasised that two categories, GoverStrat (with a score of 31.0) and Infrastructure (with a score of 24.0), placed approximately in the middle of the values. These can be rated as slightly better. The remaining two categories Talent (with score of 13.3) and Commercial (with a score of 8.6) can be considered relatively weaker.

In the case of the main components, it can be stated that they correspond to a linear combination of the original variables. The question was also to determination the variance. Each principal component was quantified by the eigenvalue of the correlation matrix.

There are several criteria when choosing the number of main components. The starting point from the cumulative percentage of the total variance can be considered the leading criterion, since it is captured by the main components. Setting the value at the level of approximately 80% is considered a scientific standard. In the implemented case, 74.26% of the variability is explained by two main components. Based on this, we determined the number of main components to be 2. Another starting criterion is the so-called Kaiser's rule. The principle of Kaiser's rule says that we keep only those main components whose variances exceed 1. In practice, this means that we keep those for which the eigenvalues are higher than 1. In our case, the first two eigenvalues are 5.45 and 1.23, which meet this condition. It means that we will continue to work with the first two main components. Table 3 presents the calculated values of the eigenvalue of the correlation matrix with the proportion of explained variance.

Tab. 3 Values of the eigenvalue of the correlation matrix and the proportion of explained variance

	eigenvalue	variance. percent	cumulative. variance. percent
Dim.1	5.449809	60.55344	60.55344
Dim.2	1.233167	13.70185	74.25529
Dim.3	0.840272	9.33636	83.59165
Dim.4	0.559841	6.220453	89.81211
Dim.5	0.369400	4.104443	93.91655
Dim.6	0.337587	3.750966	97.66751
Dim.7	0.164369	1.826326	99.49384
Dim.8	0.044665	0.496282	99.99012
Dim.9	0.000889	0.009879	100.00000

Source: own processing using software

In the next part of our analysis, we will present the results of subsequent calculations through tabular support. The tables contain the obtained results of testing the significance of the correlation coefficients between the variables and the defined first two main components. It is clear that each variable has a statistically significant relationship with at least one principal component, therefore no variable needs to be excluded from further analyses.

Tab. 4 Link between the variable and the 1st principal component

acronyme	correlation	p. value
Overall	0.9919236	3.93E-22
Talent	0.9380322	4.53E-12
Research	0.9370864	5.37E-12
Infrastructure	0.8336408	2.28E-07
Development	0.8173366	6.14E-07
GoverStrat	0.8050674	1.22E-06
OperEnviro	0.5777242	2.49E-03
Commercial	0.5567244	3.85E-03

Source: own processing using software

PC2 as a defined second component shows a strong relationship with the variables Y2019 and Commercial. The found correlation relationship between Y2019 (tourism contribution to GDP in 2019) and PC2 is 0.750 with a significantly significant p-value of 1.55E-05, which underlines that there is a substantial relationship. The situation is similar for the variable Commercial, which reflects the level of the Commercial Ecosystem. There is a correlation of 0.659 with PC2 at a p-value of 3.40E-04. This finding demonstrates a strong and significant association (Table 5). The obtained analytical results indicate that these two variables have a key role in defining the second dimension of variance in the data.

Tab. 5 Link between the variable and the 2nd principal component

	correlation	p. value
Y2019	0.7504735	1.55E-05
Commercial	0.6590504	3.40E-04

Source: own processing using software

Biplot illustrates the results of a principal components analysis (PCA), where points represent the individual countries, and blue arrows indicate the variables, which identify the main drivers of variability in the data. The first principal component (Dim1) explains 60.6% of the variability, and the second principal component (Dim2) explains a further 13.7%.

The biplot illustrates that countries such as France (FR) and Germany (DE) are significantly to the right, indicating that they score high in AI-related areas such as research, talent, infrastructure and government strategy. This suggests that these countries have a well-developed AI environment, supported by government investment and a strong research base.

In contrast, countries such as Latvia (LV), Slovakia (SK) and Romania (RO) are on the left-hand side, indicating lower values in the AI index dimensions. This may be a consequence of less availability of AI talent, weaker infrastructure or lower investment in AI research and commercialisation.

The Y2019 variable (tourism contribution to GDP) has an upward slope , indicating that it is more strongly associated with the second principal component (Dim2). This suggests that countries higher up the graph, such as Croatia (HR) or Greece (EL), have a higher share of tourism in GDP.

AI index dimensions such as Talent, Research, Development and Government Strategy are oriented in a similar direction, suggesting that countries with high scores in one of these areas often score well in the other AI factors. Specifically, countries such as the Netherlands (NL), Sweden (SE) and Denmark (DK) have higher scores in the talent and infrastructure dimensions, which may indicate a strong technology base supporting AI development.

The Commercial dimension, which reflects startup activity and investment in AI entrepreneurship, is transport-oriented. This suggests that countries that are in this direction of the chart have a stronger business environment for AI innovation.

Overall, the biplot reveals two main trends: one group of countries is characterised by a strong focus on AI and technological development, while the other group has a higher share of tourism in GDP and a less developed AI environment. This perspective allows identifying patterns across countries and understanding how AI factors correlate with economic variables such as tourism's share of GDP.

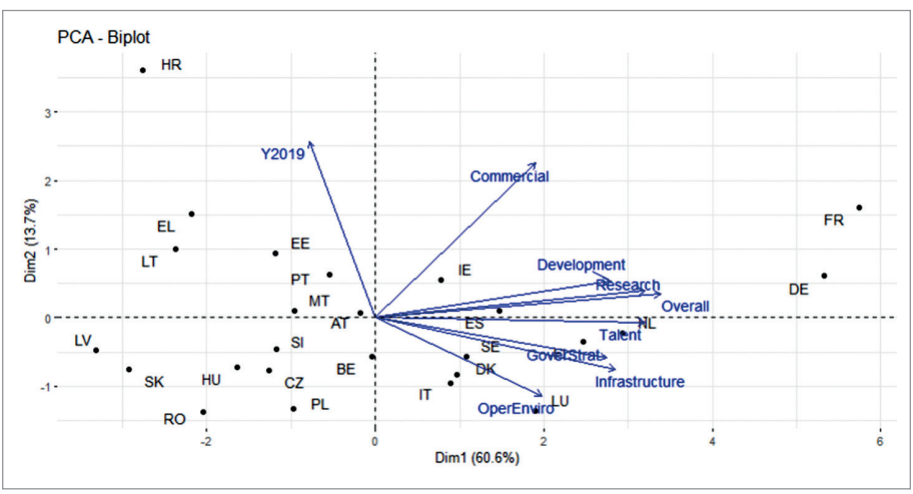

Fig. 2 Biplot

Source: own processing using software

In the next step, we proceeded to cluster analysis. The average linkage method is the best according to the agglomeration coefficient because it better preserves the hierarchical consistency in the clustering. Internal clustering validation evaluates the quality of clusters based on internal consistency and separation The single linkage and average linkage methods produce the best separated clusters according to Dunn index. Ward.D2 is the weakest, which means it may produce more compact but less separated clusters. For the above reasons, we used the average linkage clustering method. It produces balanced clusters that are neither too stretched nor too compact.

Tab. 6 Choosing of clustering method

Method	ward.D2	complete	single	average
Dunn index	0.30198	0.306598	0.531261	0.531261
Agglomerative coefficient	0.65712	0.747266	0.711874	0.82133

Source: own processing using software

Next, we proceeded to compute hierarchical clustering and validate the stability of the clusters.

In the dendrogram (Fig. 3) we cansee that the approximately unbiased p-value for the cluster of the countries Czechia, Hungary, Poland and Romania is 98 percent, i.e. the cluster is stable and considered reliable. After adding Slovakia and Latvia to the list, the cluster is relatively stable (the value of approximately unbiased p-value is 93 percent) and we can consider the clustering result as reliable.

The first cluster comprises Central and Eastern European countries with a relatively low contribution of tourism to GDP (Y2019), ranging from around 2.2% to 4.8%. The value of the overall AI index (Overall) is relatively low, ranging between 5 (Latvia) and 11 (Czech Republic and Poland).

In terms of AI talent, these countries tend to have poor to average scores, with Poland (11) and the Czech Republic (10) having the highest scores, while Romania (5), Latvia (5) and Slovakia (6) have lower scores. Infrastructure is relatively balanced, ranging between 18 and 23 points, indicating stable but not highly developed access to computing and digital capabilities.

The regulatory environment and public opinion on AI (OperEnviro) are slightly below average in these countries, with values oscillating between 47 (Czech Republic) and 66 (Romania). Research activity (Research) is very low, with most countries scoring between 1 and 4, the exception being Romania (7).

The development of basic AI platforms (Development) is poorly developed in this cluster, with some countries (Slovakia, Latvia) showing virtually no activity in this area. Government strategy (GoverStrat) is variable - the Czech Republic (45) and Poland (31) have relatively high values, while Slovakia and Latvia have zero scores, indicating the absence of a strong AI strategy.

On Commercial, countries have low scores, mostly between 1 (Romania, Latvia) and 5 (Hungary). This cluster thus represents a region with limited development of the AI ecosystem, yet notable differences exist between countries, especially regarding government strategies and the regulatory environment.

Countries in the first cluster, such as the Czech Republic, Hungary, Poland, Romania, Slovakia and Latvia, could significantly boost tourism development through AI if they focus on strengthening key dimensions of the AI ecosystem.

One of the most important factors is the development of talent(Talent) in the field of AI. Upskilling professionals and promoting education in this area would enable the creation of intelligent recommendation systems, chatbots and personalised tourist experiences. For this, a modern digital infrastructure is also essential. Investment in high-speed internet, cloud services and computing capacity would improve the availability of AI solutions for hotels, airports and tourist attractions.

Research is also an important part of promoting AI in tourism. If First Cluster countries invested more in research projects on AI in tourism, they could manage tourist flows more effectively, anticipate seasonal trends and protect cultural sites from an over-abundance of visitors. In addition to research, funding is also needed to develop AI platforms that would help optimise hotel and service prices according to current demand and enable efficient capacity management.

Supporting startups and investing in AI solutions in the tourism sector would create new opportunities for smart booking systems, digital guides and innovative services that could attract more tourists. Governments should therefore develop a strategy to effectively link AI and tourism, for example through subsidies or legislative measures to facilitate the adoption of these technologies.

If countries strengthen these dimensions, they could increase the efficiency of tourism, offer visitors more personalised experiences and increase tourism revenues. At the same time, AI innovations would help improve the competitiveness of destinations and attract modern tourists who expect smart and digital services.

In the second cluster are Ireland, Sweden, Belgium, Denmark. The approximate unbiased p-value is 96 percent, i.e. the cluster is stable (more than 95 percent) and considered reliable. The second cluster includes the economically developed countries of Western and Northern Europe. These countries have a strong position in applying AI, but their tourism contribution to GDP (Y2019) is relatively low, ranging between 1.86 percent (Belgium) and 4.76 percent (Ireland).

The overall AI index (Overall) is significantly higher in this cluster than in the first cluster, with values ranging from 14 (Belgium) to 16 (Ireland, Sweden and Denmark). These countries also have a strong talent pool, with Sweden and Denmark having the highest values in this area (17), indicating a high availability of skilled AI professionals.

Infrastructure is at a very good level, with scores ranging from 20 (Belgium) to 26 (Ireland, Sweden), indicating the robust digital and technological capabilities needed to develop AI solutions. The regulatory environment and public opinion on AI (OperEnviro) are at a high level in this cluster, with Sweden scoring as high as 88, indicating favourable legislative conditions for AI implementation.

Research activity (Research) is significantly higher compared to the first cluster, with Sweden standing out the most (8), while the other countries are between 5 (Ireland) and 7 (Denmark). The development of AI platforms and algorithms (Development) is moderately developed in these countries, with Ireland scoring highest (14), while the other countries have lower scores (5 to 6).

Governments in these countries show varying levels of commitment to AI (GoverStrat), with Denmark (44) and Ireland (31) investing more in AI strategies, while Belgium (27) and Sweden (23) have slightly lower levels of support. Commercial use of AI is relatively strong in this cluster, with Ireland and Sweden scoring highest (12).

Overall, these countries are advanced economies with good technological backgrounds and favourable conditions for AI R&D. They have the advantage of high quality talent and infrastructure, but tourism plays less significant role in their economies. If they wanted to increase the use of AI in tourism, they could focus on leveraging their technological potential to create innovative solutions such as smart travel apps, automated booking systems and tourist flow analytics.

The countries in the second cluster - Ireland, Sweden, Belgium and Denmark - already have a well-developed AI ecosystem, but tourism plays a smaller role in their economies. If they want to use AI to boost tourism, they should focus on strengthening specific dimensions that can link their technological capabilities to the needs of the tourism sector.

One of the key areas for improvement is the commercialisation of AI (Commercial). Although these countries have a solid business environment for AI startups, they should encourage dedicated investment in AI solutions for tourism. This could lead to the development of innovative booking platforms, smart destinations and personalized AI-based travel guides.

Another important step is to increase government support (GoverStrat) for AI applications in tourism. Countries such as Denmark and Ireland already have relatively strong AI strategies, but governments need to create specific programmes to fund the development of smart tourism solutions, for example for automated visa processing, digital tourist assistants and smart crowd management systems in popular locations.

These countries also have highly skilled AI talent (Talent), but it is important to incentivise professionals to get involved in developing tourism applications. Dedicated hackathons, research grants and partnerships between universities and the private sector can be organised to develop AI solutions for tourism.

Given the strong technological infrastructure (Infrastructure) of these countries, it would be beneficial to invest in the development of predictive analytical tools to optimise tourist flows, dynamic pricing of accommodation and transport or modelling of demand in different seasons. This would help to manage capacity in tourism more efficiently and at the same time increase revenues in the sector.

The overall expected impact of these measures would be to increase competitiveness in tourism, improve the quality of services and attract more tourists who value digital innovation. Linking AI to tourism could thus strengthen the economies of these countries while improving the visitor experience.

The approximate unbiased p-value for the third cluster is 99 percent, i.e. the cluster is stable (more than 95 percent) and considered reliable. It includes countries such as Portugal, Malta, Slovenia, Austria and Estonia, which are characterised by a medium contribution of tourism to GDP (Y2019), ranging from 5.33 per cent (Austria) to 8.1 per cent (Portugal). These countries have a relatively balanced level of AI ecosystem development, but with some variation across dimensions.

The overall Global AI Index (Overall) score ranges from 11 (Slovenia) to 13 (Portugal, Austria), indicating a slightly above average position in AI in the global context. The availability of AI talent (Talent) is moderately developed in this cluster, with Austria scoring the highest (15), while Malta (6) and Slovenia (8) show weaker levels of professional capacity in this area.

Infrastructure is relatively homogeneous in these countries, with values between 19 (Estonia) and 22 (Portugal, Slovenia, Austria), indicating a solid technological background for the development of AI applications. The regulatory environment and public opinion on AI (OperEnviro) is highly favourable in some countries, especially in Portugal (84) and Slovenia (76), which may support the development of AI solutions in tourism. In contrast, Estonia (59) and Austria (61) have lower scores in this area.

AI research (Research) shows large differences, with Austria (9) being the leader of the group in this area, while Malta (3) and Portugal, Estonia and Slovenia (4-5) have lower levels of publication activity and academic research in AI.

A significant gap in some countries is the development of AI platforms and algorithms (Development) - Slovenia and Estonia have a value of 0, which means that there is no significant support for the creation of AI technologies in these countries. In contrast, Malta (9) and Portugal (8) have a relatively strong development base, which allows them to create and implement new AI solutions.

The government's AI strategy (GoverStrat) differs significantly in this cluster. Malta (35) has the highest score, followed by Austria (33) and Estonia (29), indicating that these governments are actively supporting AI initiatives. In contrast, Slovenia (28) and Portugal (24) have lower levels of government commitment to AI.

Commercial use of AI (Commercial) is moderately developed in this group - Estonia (13) stands out with the highest score, indicating a strong link between

AI and the business environment, while the other countries score between 5 (Slovenia) and 7 (Portugal).

Overall, these countries represent technologically advanced economies with a stable infrastructure and a moderately developed AI ecosystem. Their strong regulatory environments and government support can be the basis for more effective integration of AI into tourism. If these countries would like to strengthen the use of AI in tourism, they should focus on developing talent, increasing research activity and supporting startups focused on AI solutions in travel services.

Countries such as Malta, Estonia and Slovenia, which have lower values in the availability of AI talent, would benefit from investing in education and training programmes. Collaboration between academic institutions and technology companies offering professional courses and hands-on training in AI applied to tourism could contribute to this. Upskilling professionals would allow AI to be used more effectively to develop personalised tourist experiences, chat bots for customer support and optimisation of tourist itineraries.

Countries such as Estonia and Austria, which have a stronger commercial environment, should focus their attention on supporting startups and entrepreneurial initiatives focused on AI solutions for tourism. Investing in innovative projects such as smart booking platforms, dynamic pricing or systems for predicting tourists' preferences could significantly streamline the tourism sector. This could enable new technologies and applications to emerge that would improve the customer experience, reduce operational costs and increase the competitiveness of tourist destinations.

Countries such as Malta and Austria with relatively high values in terms of government support should continue to develop national strategies that promote AI in tourism. This could include creating a legislative framework for the safe and ethical use of AI, as well as providing grants and financial incentives for initiatives that integrate AI into tourism services.

Given the growing emphasis on sustainability, countries in this cluster could use AI to develop solutions that help optimise tourism flows, minimise the negative environmental impact of mass tourism and improve resource efficiency. Intelligent systems could monitor visitor arrivals, analyse energy and water consumption in tourist facilities and prevent infrastructure congestion. These solutions would help to achieve sustainability in tourism, reducing environmental impact while providing tourists with a quality and efficient experience.

The approximate unbiased p-value for the fourth cluster is 90 percent. The cluster is relatively stable and the clustering result can be considered as trustworthy. The fourth cluster includes countries that show a strong presence in AI and a relatively higher contribution of tourism to GDP (Y2019). Countries in this cluster, namely France and Germany, show excellent performance in most dimensions of the Global AI Index, indicating a mature and stable AI ecosystem

that has the potential to significantly boost tourism development. France (25) and Germany (35) score very strongly in the area of Talent Availability (Talent). These countries have a rich base of AI experts, which means they are able to develop sophisticated technologies to support a variety of industries, including tourism. The significant presence of talented experts to develop, implement and optimise AI applications provides a strong foundation for innovation in the tourism sector. Germany (32) and France (31) also show excellence in Infrastructure. This means that both countries have a stable and modern infrastructure that includes high-speed internet, energy reliability and access to computing capacity, including supercomputers, which is key for the development and application of demanding AI technologies. High quality infrastructure also enables faster implementation and wider deployment of AI solutions in tourism.

In the area of regulatory environment (OperEnviro), both countries score high, Germany (83) and France (70). This indicates that they have a stable and favourable legislative framework for the uptake and implementation of AI. There are clear regulations on ethics, privacy and security, which is essential to promote user confidence in the uptake of AI in various sectors, including tourism.

In the area of Research, these countries also score highly, with Germany (16) and France (18) leading the way in the number of research publications, patents and academic achievements in the field of AI. The high research potential of these countries enables the development of innovative AI solutions that can improve the quality and efficiency of tourism services, as well as contribute to sustainability and the development of new technologies in tourism.

In the area of Development, both countries are relatively strong, with Germany (14) and France (31) investing in the development and testing of new AI algorithms and platforms. A strong focus on development enables the creation of customised and advanced technologies that can improve the forecasting of tourism trends, optimise visitor arrivals and enhance the customer experience in real time.

France (59) and Germany (59) consistently show excellent government engagement (GoverStrat) in AI. Both countries have developed national strategies and policies to support AI research and implementation, which includes funding for innovation projects, support for startups, and investment in AI infrastructure development. Strong government support for AI creates a favourable environment for the commercialisation and wider deployment of these technologies, including their application in tourism.

In Commercial, values are strong in both countries, with Germany (17) and France (19). They are in the top quartile. This suggests that these countries have high levels of commercialisation of AI innovation, including startups, entrepreneurial initiatives and investment in commercial products. The high level of commercial development enables the use of AI in practical applications that can

streamline the operation and management of tourism services, as well as increase the competitiveness of destinations.

The fourth cluster of countries is characterised by a strong and mature AI ecosystem. They have a robust infrastructure, high availability of talent, a favorable regulatory environment, and strong government support. These countries can leverage their research and development capabilities to create innovative AI solutions that could improve the quality of tourism, optimize tourism flows, contribute to sustainability, and enhance the overall tourist experience. High commercial engagement suggests that innovative AI technologies can be rapidly implemented in tourism services, which would boost tourism competitiveness and growth.

The approximate unbiased p-value for the fifth cluster is 90 percent. The cluster is relatively stable and the clustering result can be considered as trustworthy. The fifth cluster contains Spain and Italy, countries with a relatively strong position in AI and tourism's contribution to GDP (Y2019).

While these countries are not complete leaders in each area, they still show high potential for the use of AI in various sectors, including tourism. Both Spain (17) and Italy (16) score decently in the Talent domain, indicating the presence of skilled AI professionals, albeit not as strongly as in some other countries. Nevertheless, there is potential in these countries to develop and attract more AI professionals who can support the development of advanced tourism solutions such as smart booking systems, personalised offers or optimisation of tourism flows. The development of talent can lead to the creation of innovative technologies that will improve tourism experiences and operations in the tourism sector.

Spain (26) and Italy (23) score moderately in Infrastructure. Although both countries have well-developed infrastructure, their values show that there may be opportunities to improve the availability of high-speed internet and energy capacity, which are needed to effectively implement AI applications in tourism. Stronger infrastructure could facilitate the development of advanced AI solutions that enable tourists to access smart services and information in real time.

Improved infrastructure can enable faster and broader development of AI applications in tourism, including automated recommendations, predictive analytics, and more efficient bookings.

Spain (74) and Italy (100) score very high on the regulatory environment (OperEnviro). Italy, in particular, excels in its values, indicating strong legal frameworks and policy support to implement and regulate AI solutions. Spain also has very good conditions for the deployment of AI technologies, which is crucial to promote public trust and transparency in AI applications in tourism, such as services based on the analysis of tourist data and preferences. A strong regulatory environment can foster trust in AI solutions in tourism and ensure that new applications are ethical and safe for tourists.

Both Spain (6) and Italy (7) have Research dimension values in the third quartile. Research activities and strengthening innovation in AI could accelerate the development of new solutions for tourism, such as analytics tools to analyse tourist behaviour, smart bookings and personalised marketing campaigns. The research potential can foster the emergence of innovative AI solutions that will improve the prediction of tourism trends, optimisation of accommodation facilities and services.

In the area of Development, Spain scores 10, indicating a moderately active presence in this area, while Italy (2) has a lower level of development compared to other countries. This means that while there is room for the creation of new applications and platforms, these countries can still improve their capabilities in this area to match the leaders in AI.

Both countries score strongly on government strategy ((GoverStrat)). Spain 66, Italy 53, indicating that they have clear plans and support from the government to develop AI and its application in various sectors, including tourism. Strong government support may lead to a greater focus on innovation in tourism and the implementation of AI technologies. Improved government support can accelerate

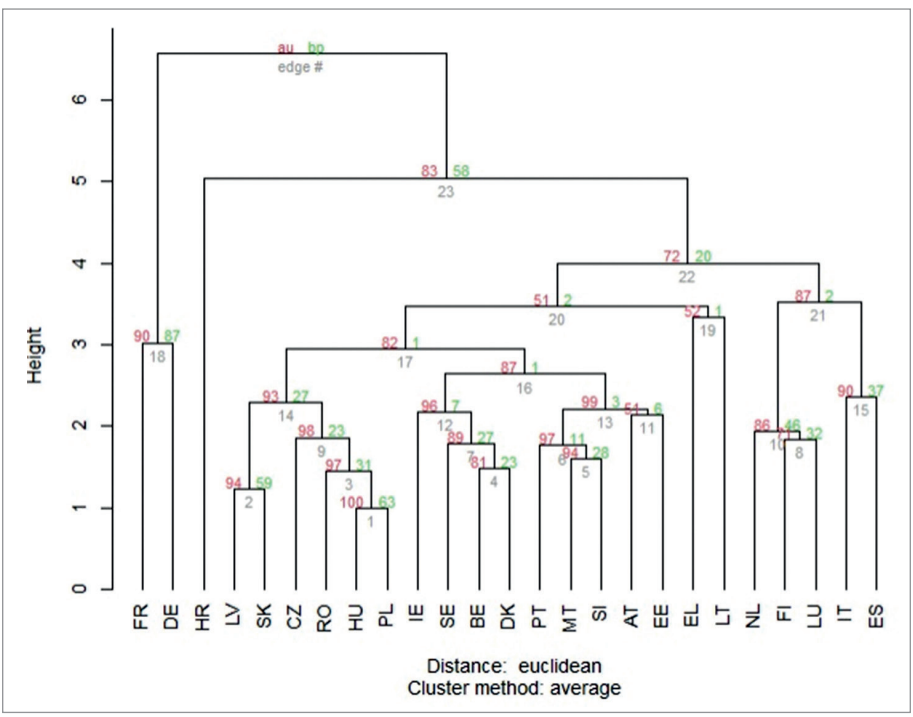

Fig. 3 Cluster dendrogram with p-values
Source: own processing using software

the deployment of innovative AI solutions in tourism, such as smart guide systems or optimised marketing campaigns.

In Commercial, Spain (7) and Italy (5) show values on the borderline of the first and second quartile. This suggests that there is room for further development and commercialisation of AI solutions in the tourism sector. Both countries can support the emergence of startups and entrepreneurial initiatives that focus on innovation in tourism through AI technologies. Greater commercialization of AI could encourage the emergence of new products and services that meet the needs of modern tourists and streamline operations at tourism destinations.

We do not comment on the other clusters because their AU (Approximately Unbiased) p-value is below 0.9. This lower index suggests that the stability and reliability of the clustering is not high enough to rely on them for data interpretation and analysis. Lower AU values suggest that differences between clusters may be less consistent and clustering could be less accurate, reducing its value as a reliable tool for detailed analysis.

CONCLUSIONS

The impact of artificial intelligence and the emerging challenges in the tourism business are becoming more and more significant. The importance of this topic is indisputable, as the deployment of AI shapes the direction and further development of the tourism industry and determines its strategic management in the context of ensuring competitiveness, sustainability of business in this sector and equitable development. New technological innovations act as a catalyst for change and fundamentally affect the entire tourism sector in terms of efficiency, automation or personalisation. In the present paper, we applied principal component analysis and cluster analysis methodology. This combination yielded the discovery and exploration of interrelationships between selected variables such as the level of AI development and the share of tourism in GDP. We have demonstrated an uneven distribution of technologies, which raises the need for more targeted support for an even and sustainable development within the European Union countries. The development of AI depends primarily on the development of infrastructure, the availability of high-speed and broadband internet connectivity, qualified IT professionals, commercial integration into individual business processes and, last but not least, on the public policies in place to support investment in the expansion of AI. Our analysis revealed a lag in the development of AI technologies in the post-communist countries such as Slovakia, the Czech Republic, Romania, Latvia, Croatia, but also in the case of Greece. The findings can be a useful starting point for creating and shaping new development policies and investments in the application of artificial intelligence in tourism. Our analysis is based on data from 2019, due to the fact that it was the most recently observed year with relatively stable travel and economic conditions prior to the outbreak of the pandemic

disease COVID-19. The pandemic has fundamentally and broadly changed the conditions for tourism, which may not be included in the present research study. Based on the results, we have highlighted significant differences between EU Member States. However, it is important to note that not all countries provide data of the same quality, and in some cases, data availability is limited. Therefore, the data obtained will not capture all externalities, specificities or nuances resulting from locally specific legislative, economic or socio-cultural conditions. PCA is based on linear relationships between variables and thus may not capture all interaction relationships between tourism and AI. The analysis performed does not assess the long-term trends of AI development in tourism. The above could help to predict future directions and development phases. Based on our findings and identified challenges, we formulate the following possible research directions for the application of artificial intelligence in tourism: there will be a need for a deeper investigation of the differences in the use of AI across the European Union countries, with emphasis on regional infrastructural, economic or socio-cultural differences; there will be a need to identify and formulate specific public policies and investment strategies to address the regional disparities between less developed and developed EU countries; we recommend that longitudinal studies be carried out with the intention of assessing the development dynamics of AI over a longer time horizon; the impact of AI deployment and scaling-up on macro-economic (economic growth, employment, etc.) indicators will need to be investigated; the impact of AI deployment and scaling-up on macro-economic (economic growth, employment, etc.) indicators will need to be investigated.), on business-economic (customer preferences, customer satisfaction, etc.) and technological (synergistic relationships between AI and technology) indicators. For future research, we also identify opportunities for specifically focused research reflecting on the application of AI for individual forms of tourism such as mass tourism (e.g. automation of services for large volumes of tourists), luxury tourism (e.g. provision of personalized high quality services), ecotourism (e.g. finding optimization solutions for green sustainability and environmental protection).

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MICROCLIMATIC CHALLENGES IN THE CONSERVATION OF WOODEN SACRAL MONUMENTS OF CULTURAL HERITAGE: A CASE STUDY OF A WOODEN CHURCH IN RĂSTOLȚU DEȘERT (ROMANIA)

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Abstract
The study aims to investigate the impact of the internal microclimate factors of wooden sacral buildings on the quality of their visitors' experience, using the example of protected cultural heritage objects of local significance, with higher

conservation requirements. The topic of the study is a relevant contribution to the ongoing debate on the sustainable conservation of tangible cultural heritage, especially in the context of polycrisis, particularly climate challenges and the increasing demands of their visitors for an authentic tourist experience. Using the example of a protected wooden religious building from Romania, it highlights the close link between the physical protection of monuments, the health of visitors and the quality of their experience. The research was conducted over a period of one year (February 2024 - February 2025) through continuous measurement of indoor environmental parameters (temperature, relative humidity, CO_2, PM2.5, PM10, VOCs, formaldehyde, lighting and noise) in the cultural monument under study. A second set of primary data, obtained from a parallel survey conducted on a sample of 90 cultural heritage monument visitors, was also examined. The survey focused on the respondents' perception of indoor air quality and its impacts on their health. Generalized regression analysis was used to test the relationship between the indoor environment of the monument and the symptoms described by respondents. The study revealed significant deviations from international standards of protection. Indoor temperatures varied from -6.4 °C to 29 °C, with an average relative humidity of 70.83 %, which favoured the growth of micro-organisms. CO_2 and dust particle levels were highest during religious ceremonies and correlated with discomfort (dry throat, sneezing, stuffy nose). Statistical analysis confirmed that individual characteristics such as medication use and exposure to pollution influenced these symptoms. Visitors most frequently identified dry and stale air as negative factors but they appreciated the authentic atmosphere of the temple. The study provides a unique data-driven perspective on the complex relationship between conservation conditions and the authenticity of the visitor experience at vulnerable cultural sites. It highlights the importance of microclimatic monitoring in preventive conservation and promotes the use of adaptive technologies to preserve heritage while ensuring the health and comfort of visitors. The results can support practitioners in finding a balance between physical protection and meaningful public access to heritage sites.

Keywords
Tourism, cultural heritage, authenticity, cultural heritage conservation, cultural heritage degradation.

INTRODUCTION

Cultural heritage conservation is an essential part of protecting the cultural identity of the place it represents - from the national and regional to the local level. It is a source of national pride but also a basic differentiating feature used in national branding (Matlovicova, 2024; Matlovicova et al. 2016). Thus, the protection of cultural heritage is also pragmatically motivated as a potential source of income generated by tourism and related sectors, or in a broader context, as a tool for the socio-economic development of regions (localities) and indirectly contributes to improving the quality of life of local communities.

Cultural heritage monuments are one of the pillars of tourism development in most tourist destinations. Their potential to attract tourists is developed within the framework of numerous variations of cultural tourism, the basis of which are not only tangible but also have intangible cultural value (Matlovicova et al.,

2014; 2015). In some studies, this form of tourism is also referred to as cultural heritage tourism (Matlovicova et al., 2015, 135). In this case, it is based on all manifestations of culture as a whole, both tangible and intangible results of human activities, which are collected, preserved, conserved or evaluated and passed on to the next generations (Matlovicova et al., 2015; 2016). Thus, the conservation of cultural heritage sites represents one of the key challenges in the field of heritage conservation and sustainable tourism development (Sumarmi et al., 2021).

This study focuses on one element of cultural heritage, represented by the monuments of material culture bequeathed to us by previous generations, specifically wooden sacral objects of high cultural and social value, which are subject to protection. Therefore, this study aims to investigate the influence of the factors of the internal microclimate of wooden sacral buildings on the quality of the experience of their visitors, using the example of protected cultural heritage objects of local significance with high conservation requirements. The findings of the research will be used in a broader context to optimise the management of the conservation of historically valuable objects to minimise the risk of deterioration of the monuments and at the same time, promote their active integration into the tourist offer.

In the context of the current socio-economic changes we face, which are strongly influenced by the consequences of the polycrisis, the sustainable conservation of cultural monuments is a significant challenge. It requires a transdisciplinary approach that takes into account the full range of possible impacts on the objects of conservation. The synergistic effects of the interaction of numerous crises (not only environmental but also economic, social and political) make the management of cultural heritage at all levels much more difficult than ever before (see Matlovic and Matlovicova, 2024). This is a very challenging task because any intervention in the historical structure of a monument should take into account not only its physical protection but also the preservation of the authenticity of the experience that this protected object conveys. Authenticity is not only a matter of preserving original materials and techniques but also preserving the atmosphere and feelings associated with the monument. Sustainable conservation of cultural heritage therefore requires the involvement of a wide range of actors—local communities, public institutions, private sector actors and professionals in the fields of conservation, tourism and regional development (Boros et al., 2024; Herman et al., 2020, 2022; Matlovicova, 2008).

CULTURAL HERITAGE CONTEXTUALISATION

The definition of cultural heritage has been the subject of extensive debate for decades. According to Muñoz-Viñas (2023, p. 131), the initial perception of cultural heritage reflected its material—the physical nature of objects of exceptional historical or artistic value. As the author further states, it is only later that a non-

axiological discourse emerged that included the tangible objects of protection as well as the intangible elements of cultures.

According to Ashworth (2012, pp. 4-11), the evolution of views on the content of heritage has been formed successively in three distinct stages: Stage 1 in which conservation and the development of relics of the past are considered contradictorily. "*Development is thus seen as the antagonist in the process of preserving relics of the past for the future. Any attempt to compromise with the paradigm of preservation of the past leads to undermining preservation or underdevelopment. Thus, in this case, the goal of 'save by developing' is ruled out*" (Ashworth, 2012, pp. 4-11), Stage 2 in which adaptive reuse of relics of the past is also accepted, and finally, Stage 3 in which, according to Ashworth (2012), objects of conservation are seen as a transmissive means of historically contributing to many current social, political and economic needs, where selected relics of the past, events or parts of history are presented in the present (Ashworth, 2012, pp. 4-11). Thus, paradoxically, according to Ashworth (2012), the main goal is not so much the preservation of something from the past but the use of the past for present purposes as a determinant of the generation of further resources. In this case, heritage is approached as a product, using sophisticated strategies to increase the 'sale' of heritage—heritage marketing (Matlovicova, Husarova, 2017; 2024).

In the current discourse on the theoretical frameworks of the concept, there is also an approach that blurs the boundaries outlined above by considering everything natural and cultural that currently exists as heritage. However, as Muñoz-Viñas (2023, p. 131) notes, such an approach, which is considerably vague from the perspective of theoretical clarification, can lead directly to some forms of panheritage or even theoretical nihilism.

Conversely, setting boundaries from the perspective of the significant impact of the objects of conservation has been the subject of extensive debate, leading in 1972 to the World Heritage Convention (UNESCO, 2016). The document states that there are exceptional places in the world that deserve special protection to preserve them for future generations for as long as possible. In terms of management for the conservation of World Heritage (not only), the role of local communities is specifically highlighted, for which the Convention (UNESCO, 2016) serves *"as a means to address issues related to climate change, rapid urbanization, mass tourism, sustainable socio-economic development, natural disasters or other contemporary challenges"*.

In this context, drawing on the work of Ashworth (1997; 2012), natural and cultural heritage can be seen as a process through which objects, events, places, practices, personalities and their interpretations „*derived from the past are transformed into experiences in and for the present*" (Ashworth 1997; 2012, p. 2, 3). Heritage represents a deliberate and intentional product of contemporary political, social, or economic exigencies. (Ashworth, 2012, p. 2, 3). Defined in this way,

heritage must be understood from the outset not only as an approach that was, but that is, a means for understanding the past in the present (Ashworth, 1997).

Heritage, therefore, needs to be seen contextually and, according to Ashworth and Graham (2005), in the plural, that is to say, bearing in mind multiple possible pasts or cultural and natural heritages concerning a given object. Consequently, this implies a diversity of possibilities for the use and creation of marketing products based on a multiplicity of heritage producers—both public and private, official but also unofficial, own and foreign (in the sense of origin; Ashworth & Graham, 2005). Satisfying them in terms of achieving the intended goals is a major challenge as they are usually quite different. Therefore, often most of the effort in the planning process is devoted to trying to reconcile different ideas about heritage management.

From the perspective of the management of tangible cultural heritage, which is the focus of this study, we are dealing with practices that lead to extending the life of conservation objects for as long as possible.

CONSERVATION OF CULTURAL HERITAGE OBJECTS AND AUTHENTICITY

The conservation of cultural heritage is understood as an active cultural intervention, often also requiring "sophisticated techniques and skills to modify the objects of conservation so that they can better perform their assigned function" (Muñoz-Viñas, 2020, p. 7), making them more active from a tourism perspective and thus better able to fulfil an informative and educational function. The protection and conservation of heritage is referred to as a social duty that is meaningful even though every physically existing object has a finite lifespan and will one day succumb to time (Muñoz-Viñas, 2023). Conservation, in the sense of Muñoz-Viñas (2023), is thus understood as a quintessence—a necessary practice that is inherent in the very notion of heritage.

In terms of the focus of our research, numerous studies have been carried out to investigate the impact of external factors on the degradation of heritage objects. For example, Nawalany et al. (2020) and Nawalany et al. (2021) conducted research on the temperature and humidity conditions in a wooden church in southern Poland, and the research results indicated that the temperature and humidity values systematically exceeded the values allowed for historical buildings, and during the use of wooden churches, the number of people in the church influences the oscillations of internal parameters. Regarding the mechanical risk created by the climate, the temperature and relative humidity standards in stave churches in Norway were investigated (Califano et al., 2022). Haisheng Hu analyzed the impact of climatic and meteorological conditions on wooden churches in the vicinity of Krakow, Poland (Hu, 2024). In Latvia, two wooden churches were included in a study, where temperature and humidity behaviour were analyzed and the conservation

limits of the microclimate parameters of the indoor air were highlighted (Metals et al., 2024). In wooden churches in Sweden, the risks of deterioration caused by fluctuations in microclimate parameters were assessed for painted wooden surfaces (Califano et al., 2024). Other similarly focused research includes several studies on the topic of indoor microclimate in wooden churches. The air quality in a wooden church in Bucharest was analyzed and interpreted, sampling atmospheric pollutants and microclimatic factors of temperature and relative humidity, to help with preventive conservation (Bucur et al., 2015). The microclimate and its impact were investigated in different environments (Cicort-Lucaciu et al., 2011) indoors in a wooden church and from the point of view of microclimatic and microbiological parameters (Ilies et al., 2018; Ilies et al., 2022). The particularities of the indoor microclimate in three wooden churches in the city of Oradea were highlighted. The analysis and interpretation of the data revealed that the indoor microclimate was not optimal and posed a potential risk to the structure of the building and human health (Mihincau et al., 2019a, 2019b; Ilies et al., 2020). Onet et al. (2020) analyzed the indoor microclimate in a wooden church in terms of temperature, relative humidity, carbon dioxide, and microbiologically. The indoor microclimate of a wooden church in Oradea was investigated for the preservation of textiles, highlighting the importance of microclimatic parameters (Ioan et al., 2020). The wooden church in Boianu Mare was analyzed from a microclimatic point of view. The fungal load of the air and surfaces highlighted the need to preserve the wooden church, and the indoor microclimate posed a potential risk to human health (Marcu et al., 2021).

A question that arises in the context of efforts to conserve cultural heritage objects that are more susceptible to degradation is whether the measures taken to protect them could reduce the level of their authenticity and thereby reduce the quality of the visitor experience.

Some research (e.g. Dai, Zheng & Yan, 2021; Ibbetson, 2000; Gregorini et al., 2019; Fernandes, 2004) shows that proper awareness is key in this regard. In other words, if visitors were sufficiently informed about the significance and cultural and social value of the site they are visiting, they would be willing to endure a higher level of discomfort as a price for the authenticity of the experience. Of course, in this respect, it should be noted that there will always be a group of visitors, and also local residents, who will not perceive the restrictions positively. However, in this regard, it is necessary to search for a compromise that will guarantee the protection of valuable cultural heritage while also allowing for socio-economic development in the area of their location (Chheda et al., 2024; Qi, 2023; Bunu et al., 2021). For example, Samah et al. (2021) underscore the importance of modern technologies, which in many ways provide opportunities not only for the protection of valuable heritage sites but at the same time new ways to enhance the tourist experience (e.g. the use of virtual reality). Although many studies point out that the substitution or augmentation of reality using modern technologies (e.g. immersive

virtual reality) cannot replace the authentic experience, it is nevertheless in many respects a suitable (often the only) alternative to enable the development of tourism in sites or objects of high cultural and social value, extremely degradable, or extremely sensitive to external influences, or that are currently showing a high degree of deterioration. On the other hand, modern technologies also bring new possibilities to enhance the quality of the experience (e.g. augmented virtual reality). This is confirmed by numerous studies conducted during the recent COVID-19 pandemic, which showed high levels of visitor satisfaction with virtual experiences (e.g. Alkhaliel, 2022). This is because new digital technologies have been shown to increase the accessibility of information and the acquisition of new knowledge and experiences in an interactive way that the analogue world does not allow. Thus, taking into account all the above-mentioned attributes of cultural heritage protection requires an extremely sensitive approach to setting tourism development plans.

AIM AND OBJECTIVES

The study aims to investigate the impact of the internal microclimate factors of wooden sacral buildings on the quality of the experience of their visitors, using the example of protected cultural heritage object of local significance, with higher conservation requirements.

The object of the research is to examine the risk factors increasing the degradation of the object of conservation over a period of one year. The objects of measurement were: temperature fluctuations, relative humidity, CO_2, volatile organic compounds, PM2.5 and PM10 particles, formaldehyde, natural and artificial light during the mentioned period, which accelerate the degradation of wooden buildings. The above measurements will then be evaluated in relation to their impacts on the overall visitor experience of such buildings. Finally, possible conservation measures for wooden religious heritage buildings will be discussed with regard to the balance in setting appropriate conditions of the indoor microclimate between measures to ensure slowing down the degradation processes of the monument and the quality of the experience of its visitors. In other words, that conservation measures do not lead to limitations in the use of the heritage object and to a reduction in the authenticity of the internal environment.

The object of research is a wooden sacral building—the wooden Church of the Assumption of the Virgin Mary in Răstolțu Deșert (Romania; Figures 1 & 2). The heritage object under research represents an authentic part of the culture of the local community. It is not only used by the local community as an important local centre of social life but also serves visitors who regularly attend local sacred and secular events. The church dates from the early 19th century (Ministry of Culture, 2015). Notable for its high tower, it was built on a rectangular plan with a detached, polygonal apse with five sides (Godea et al., 1978). The church was small and in

1846, to enlarge it, a bay was added to the nave and the altar was moved to the east (Godea et al., 1978; Măruțoiu et al., 2017). On the south side, the nave was closed, creating the deaconry (Godea et al., 1978; Măruțoiu et al., 2017). The painting dates from 1810 and, according to Măruțoiu, was made by Ioan Pop from Românași, where we find the Passion of Christ, the Last Supper, St. Elijah with the Chariot, the Parable of the 10 Virgins and Figures of Myrrh-bearers (Godea et al., 1978: Măruțoiu et al., 2017). The Church of the Assumption of the Virgin Mary in Răstolțu Deșert (Romania) was, and still is, at the centre of several restoration actions. The ARHAIC-Ambulance for Monuments Sălaj Association replaced the church's sheet metal roof with shingles (Monumentum Association, 2020). The Sălaj County Council contributed to the consolidation of the stone foundation, the replacement of the flooring, and the conservation and restoration of the interior painting (Monitorul de Sălaj, 2023).

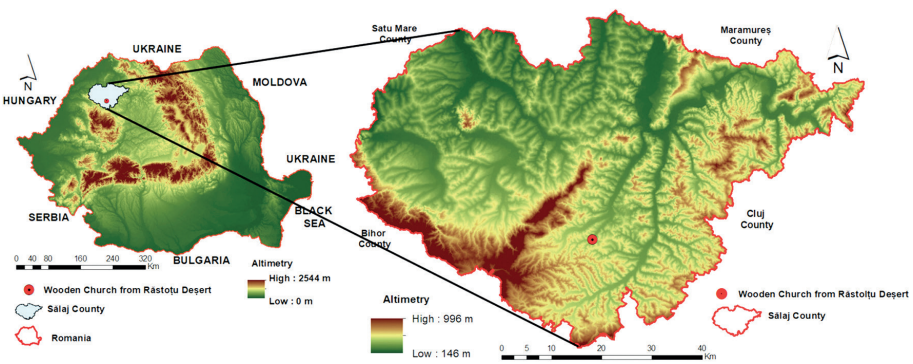

Fig. 1 The location of the wooden church in Răstolțu Deșert at the level of Romania and Sălaj county

Fig. 2 The wooden church is a historical monument in the locality of Răstolțu Deșert

DATA AND METHODS

The research was based on two types of datasets obtained through primary research. The first dataset was obtained from extensive measurements of the indoor microclimate characteristics in the protected wooden heritage structure, which lasted for one year, from 12 February 2024 to 11 February 2025. The time scale of the measurements was determined considering the macro-geographical location of the studied site in the temperate climate zone so that the measurements covered all four seasons of the year. The subjects monitored were the values and maximum annual amplitudes of the monitored indicators, which are considered to be significant determinants of the degradation of vulnerable wooden objects of cultural heritage.

Table 1 Specification of the measuring equipment used

Sensor model	Determined indicators	Precision
CO_2 air quality data logger BZ30	Temperature, RH, CO_2	±1 °C (temperature), ±5% (RH), ±75 ppm / (CO_2)
BL30 climate data logger	Temperature, RH	±1 °C (temperature), ±3% (RH)
CEM DT-96 mini particle counter $PM_{2.5}$, PM_{10}	Temperature, RH, $PM_{2,5}$, PM_{10}	±1 °C (temperature), ±5% (RH), up to ± 5% ($PM_{2,5}$, PM_{10})
CEM DT-93 Formaldehyde and Total Volatile Organic Compounds HCHO/TVOC Detector	HCHO, TVOC	±2% (VOC), ±2% (HCHO)
Split type lux meter GM1030	Temperature, Natural light LUX	±1 °C (temperature) step X1 - ±3%rg +5digits step X10 - ±3%rg +10digits stepX100 - ±4%rg +10digits gearing X1000 - ±4%rg+10digits
Sound level meter SL400	Sound level	IEC 61672-1 class 2, ANSI S1.4 type 2

Source: Trotec (2024); CEM (2024); Benetech (2024)

Monitoring of indoor microclimate indicators of the wooden religious structure was carried out at different times of the day, depending on their nature (Ilies et al., 2022). Temperature, humidity and carbon dioxide were automatically monitored at an interval of 60 minutes, over a period of one year, using a BZ30 CO_2 air quality data logger sensor (Temperature, RH, CO_2) and two BL30 climate data loggers (Temperature, RH). The accuracy of the sensors is indicated in Table 1. The sensors were positioned to cover the area of the church interior maximally, one BL 30 climate data logger sensor in the narthex and altar, and one BZ30 CO_2 air quality data logger sensor in the nave. The sensors were positioned at a height of 1.5m

(Fig. 3). Particulate matter (PM2.5, PM10), total volatile organic compounds (VOC), formaldehyde (HCHO) and natural light (NL) were recorded three times a day, in the morning (07:30), at noon (12:00) and in the evening (19:30), using 23 collection points (6 points in the pronaos, 12 in the nave and 5 in the altar; Fig. 3), covering the maximum area inside the wooden church. Sound level monitoring was done weekly, for two hours during services and a further three hours per week according to a specified schedule.

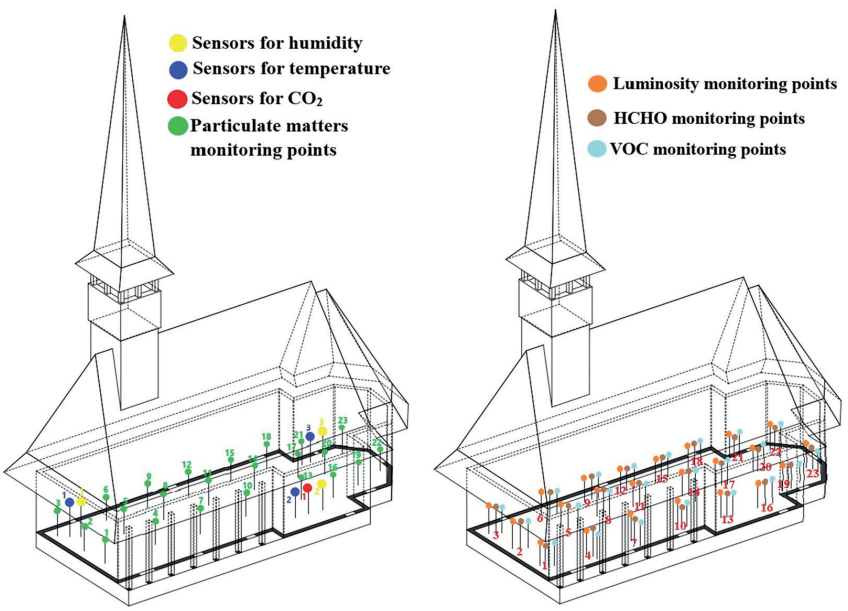

Fig. 3 Spatial distribution of sensors and data collection points

Undue values of the indicators as well as their high fluctuations contribute to the undesirable spread of fungal and bacterial micro-organisms, which not only directly damage the protected structures, but also contribute to an increased level of discomfort of visitors and, in extreme cases, cause damage to their health. For this reason, the above measurements were supplemented by a survey of visitors' perceptions of indoor air quality in the church. The survey was conducted between 01 August 2024 and 15 September 2024 on a sample of 90 respondents, who were visitors to the wooden Church of the Assumption of the Virgin Mary in Răstolțu Deșert (Romania). These were semi-structured interviews based on 31 questions divided into two thematic areas:

(a) perception of disturbances in the space of the object of study,
(b) identification of potential clinical symptoms - adverse reactions of the organism to the indoor air of the object.

Both sets of questions pertained to the activities carried out during the visit to the wooden structure under study, independent predictors of sensitivity to interior disturbances determined by daily activities in the space outside the object under study, as well as independent predictors of symptoms triggered by the visit into the interior of the object of study (both sets of characteristics are described in detail in Table 2) and finally, in relation to other identifying personal characteristics of the respondents (description below).

The demographics of the sample were as follows. 46.7% of respondents were younger than 30 years of age, 10% were between 30-45 years of age, 25.6% were between 45-60 years of age, and 27.8% were 60 years and older. Women accounted for 55.6% of the sample (of which 2% were pregnant). Regarding education, the sample was dominated by respondents with secondary (high school) education (53.3%), 35.6% had primary education and 11.1% had higher (university) education. 45.6% of respondents were of working age and employed, 22.2% were retired, and 11.2% comprised housewives. The independent predictors of sensitivity to the disturbing elements of the interior of the object under study were 14.4% of respondents were smokers, 5.6% wore contact lenses, 47.8% took medication regularly, and 24.4% had diagnosed chronic health problems or allergies.

Table 2 Independent predictors of respondents' sensitivity to indoor air quality

		%
How far do you live from this space?	Less than 1 km	52.2
	6-10 km	42.2
	More than 20 km	5.6
What is the main mode of transportation to this space?	On foot	36.7
	Bicycle	20.0
	Personal car	12.2
	Public transport (bus, train)	3.3
	By car, motorcycle	27.8
On average, how long does the trip take one way to this space?	Less than 15 minutes	64.4
	31-60 minutes	35.6
On the way, pass through the zones which could affect air quality?	Heavy vehicle traffic	4.4
	Sites under construction	1.1
	Agricultural areas	32.2
	None of the abovementioned	62.2
What is the main reason for the exposure to potential air quality risks?	Work	21.1
	Educational	6.7
	Recreational activities	8.9
	Home	63.3

		%
How often do you experience poor air quality during your commute?	Never	17.8
	Rarely	44.4
	Sometimes	34.4
	Often	3.3
Which of the following best describes the area you live in?	City centre	1.1
	Rural	95.6
	Mixed	3.3
In your daily life outside this space, how often are you exposed to polluting chemical products?	Never	33.3
	Rarely (less than once a month)	37.8
	Occasionally (1-3 times a month)	23.3
	Frequently (1-3 times a week)	4.4
	Daily	1.1
How often are you exposed to extreme temperatures in your daily activities?	Never	12.2
	Rarely (less than once a month)	41.1
	Occasionally (1-3 times a month)	37.8
	Frequently (1-3 times a week)	8.9
What is the level of exposure to noise during your daily activity?	Low (quiet environment)	36.7
	Low (occasionally)	30.0
	Moderate (ordinary urban noise)	31.1
	High (high intensity noise)	2.2
Which of the following health risks are you most frequently exposed to in your daily life?	Chemical products	18.9
	Extreme temperatures	13.3
	Loud noise	2.2
	Work at night	1.1
	Alternative changes	24.4
	Repetitive work	40.0
How would you rate your overall daily exposure to health risks outside of this space?	Very small	16.7
	Small	33.3
	Moderate	48.9
	Great	1.1

Relevant to the objectives of the study, the following hypotheses were statistically tested in the second phase of the research:

$H1_0$: There is no association between participants' individual characteristics and the number of bothering environmental factors reported within the space.

$H1_1$: There is a significant association between one or more of the participants' individual characteristics and the number of bothering environmental factors reported.

$H2_0$: There is no association between participants' characteristics and the number of symptoms experienced inside the church.

$H2_1$: There is a statistically significant association between one or more of the participants' characteristics and the number of symptoms experienced.

To test the above hypotheses, we used generalized linear regression analysis, and RStudio software (R version 4.3.1) was used to create the regression model. Independent predictors of bothering factors and symptom counts were identified through backward stepwise multivariable generalized linear modelling. A significance level of $p < 0.05$ was used for all statistical tests.

RESULTS AND DISCUSSION

Indoor microclimate and its influence on the protected wooden church

For optimal preservation of the historical monument and the comfort of the people working or using the monument, the parameters of the indoor microclimate should not fluctuate greatly. They should be maintained according to the international ASHRAE standard (ASHRAE Handbook–HVAC Applications, 2011), at an average temperature of 20°C (±1°C –2°C), and for a relative humidity of 50% (±3%).

Because the wooden church did not have a heating and ventilation system, and some windows were damaged, the internal microclimate was closely conditioned by the external climate. The average temperature value during the study period was 11.67°C and did not correspond with the international ASHRAE standard. The thermal amplitude of the internal climate was large, with a value of 35.4°C. The maximum temperature value of 29°C was recorded on July 14, 2024, at 18:49, and the minimum value of –6.4°C was recorded on two days in different months. The first recording was on January 16, 2025 at 07:21 and the second recording was on February 11, 2025 at 08:21.

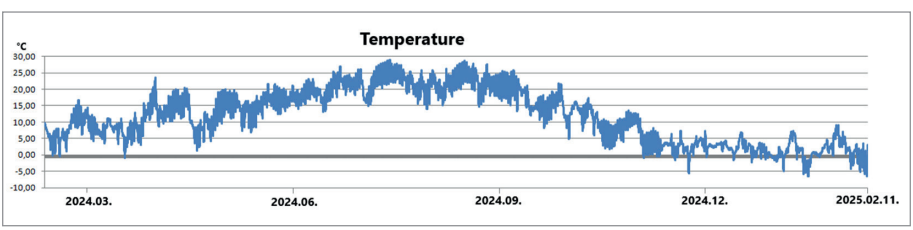

Fig. 4 Indoor temperature fluctuations (°C) from February 12, 2024 to February 11, 2025

The relative humidity inside the church had high values and presented an average value, during the study period, of 70.83%, with a maximum value of 89.20% recorded on December 10, 2024 at 2:52 PM and a minimum value of 30.10% recorded on September 8, 2024, at 7:19 PM.

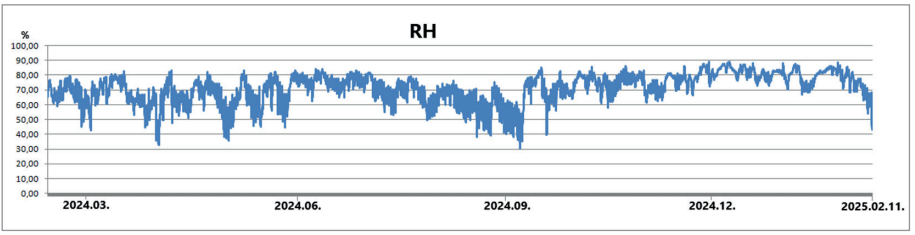

Fig. 5 Indoor humidity fluctuations (%) from February 12, 2024 to February 11, 2025

The temperature and relative humidity values were not within the optimal values and hence the microclimate inside the church was not optimal for human health and for the preservation of the objects inside; in fact, the high humidity favoured the appearance of fungal colonies (Dannemiller et al., 2018), which will be detailed in a future study. Preliminary results regarding the load of cultivable fungi, obtained by the Koch sedimentation method, indicated the indoor air contamination values ranged from medium (157.18 ± 1 colony-forming units CFU/m^3) to very high (1047.89 ± 13.33 CFU/m^3). The most frequently isolated genera were *Alternaria, Actinomucor, Penicillium, Epicoccum, Coniochaeta, Aureobasisdium, Didymella, Aspergillus* and *Cladosporium*. Except for the genus *Actinomucor*, all others have been mentioned in other studies on wooden churches or are known to degrade wood and plant cell walls (Lopez et al., 2007; Isola et al., 2024; Radu et al., 2020; Horvath et al., 1976). *Actinomucor* can usually be found in soil, with soil-dwelling genera often reported in indoor air due to their relocation from the external environment (Khan & Karuppayil, 2012).

The interior microclimate of the church was conditioned by the exterior microclimate. The periods with the maximum and minimum values of the interior temperature align with the periods of the exterior climate, and the closeness between the average temperature values during the study period can be noted—interior 11.67° and exterior 11.8°C. In terms of the relative humidity, the average value inside the wooden church (70.83%) was influenced by the exterior climate (72.44%), and the close average values of the relative humidity are notable. During the study period, the average value of the CO2 concentration was 429.18 ppm, with a maximum value of 1103 ppm recorded on August 8, 2024, at 8:00 PM and corresponding to the time of the religious service for the church's patron saint. The minimum value was 384 recorded on November 22, 2024, at 10:53 AM. The CO2 concentration values mostly varied between 400-500 ppm, while periods with values higher than 1100 ppm were recorded during religious services, due to the large number of parishioners and the oppressive air. The access path (door) remained open, influencing the value of the CO2 concentration, and contributing to the reduction of the values.

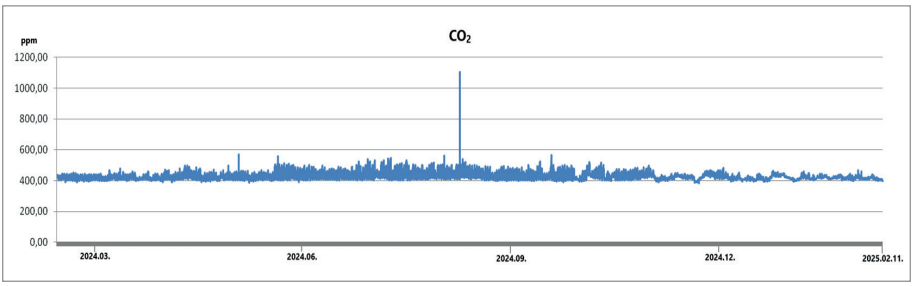

Fig. 6 Indoor CO_2 fluctuations (ppm) from February 12, 2024 to February 11, 2025

The analysis of the CO_2 concentration in the monitored wooden church fell within the standards of the ASHRAE position document on indoor carbon dioxide, American Society of Heating and ANSI/ASHRAE Standard 62.1-2010, Ventilation for acceptable indoor air quality, which provides for a concentration < 1000 ppm.

The PM2.5 concentration values fluctuated inside the church, ranging from the lowest at 0.00 µg/m^3, with the maximum reaching as high as 24.00 µg/m^3. The higher values occurred in the more closed spaces. During various activities in the church, the PM2.5 level increased due to the existing carpets and textiles, as well as the presence of dust that accumulated inside and penetrated from the outside through the damaged and degraded windows. As can be seen in Figure 7a, in the spatial distribution of the average PM2.5 values, higher values were found in the narthex (at the entrance to the church) and in the altar, and the lowest values were in the nave.

For PM10, the values fluctuated within the church, ranging from lows of 0.00 µg/m^3 to highs of 29.00 µg/m^3. The spatial distribution of PM10 followed the PM2.5 pattern, with higher values in the narthex and altar, and lower values in the nave. PM10 concentration values were influenced by textiles, damaged windows and reduced dust removal.

VOC concentrations fluctuated within the church between a minimum value of 0.47 mg/m^3 and a maximum value of 3.20 mg/m^3. The spatial distribution of VOC, as seen in Figure 7c, had higher values in the narthex and altar, and lower in the nave. TVOC are a group of critical pollutants. According to the World Health Organization and Directive 2000/39/EC, optimal values are at the threshold of < 1 mg/m^3.

Inside the church when there is no activity, the values remained constant at 0.01 mg/m^3, both in the narthex, nave and altar. During services, the HCHO concentration value reached the threshold of 0.05 mg/m^3. According to the United States Environmental Protection Agency, the optimal level of formaldehyde HCHO is < 0.004 mg/m^3.

The British Standards Institution dictates brightness values for both natural and artificial light of between 50-200 lux. Inside the church, natural light is influenced by the distribution of windows, as seen in Figure 7d, where we find average values

of between 2 and 320 lux, with lower values in the narthex and at the joints of the structure. The extreme values of natural light were between 0 and 490 lux, influenced by the external environment, where natural light values on sunny days reached a maximum of approximately 147,000 lux. Artificial light was closely linked to the lighting fixtures, and inside the church, there were 3 lighting sources—the first in the narthex, the second in the nave (candelabra) and the last in the altar. The values of artificial light fluctuated between 20.2 and 145 lux. The highest values of artificial light were in the area close to the coverage of the lighting fixtures, as seen in Figure 7e.

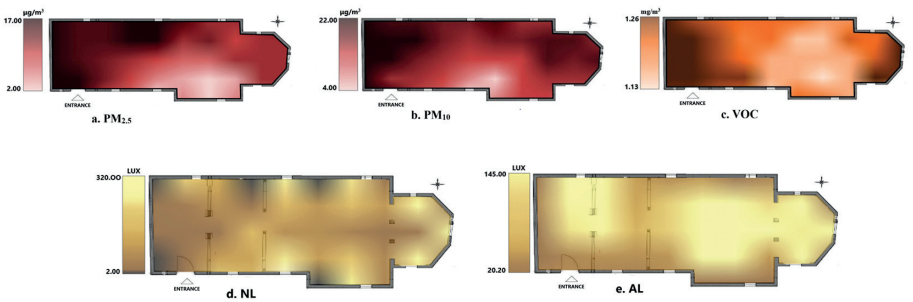

Fig. 7 Indoor average values of PM2.5, PM10, HCHO, VOC, NL and AL for each monitoring point - (a) Particulate matter PM2.5, (b) Particulate matter PM10, (c) Volatile organic compounds VOC, (d) Natural light, (e) Artificial light

The two main indicators of indoor microclimate, temperature and relative humidity, influence PM concentrations and human health (Jo et al., 2017; Zuo et al., 2021). Simultaneously, temperature and relative humidity increase the amount of PM2.5 and PM10, which increase the risk of respiratory and cardiovascular problems in the human body (Hernandez et al., 2017). Some studies associate the occurrence of lung cancer and cardiovascular diseases with long-term exposure to PM10 (Saini et al., 2021). High values of relative humidity can increase the risk of mould development, which poses a risk to human health (Freitas et al., 2010; Caciora et al., 2024).

The level of acoustic intensity is important because as the decibel level increases, the noise is more difficult to tolerate and exposure to high sound intensity can have negative consequences on the human body such as sound fatigue, headaches, increased pulse, anxiety, stress attacks, hypertension and digestive diseases (Mureşan, 2022; Roșca, 2023). Within the church, the levels of acoustic intensity had acceptable thresholds when religious services were not being held with average values between 35-40 dBA, but during religious services, the level of acoustic intensity increased. During the service on 08.08.2024, between 19:02:19 and 20:14:04, the acoustic intensity values had an average value of 67.44 dBA, and the values fluctuated as seen in Figure 8, with a minimum value of 35.7 dBA recorded at

19:02:19 at the beginning of the service and a maximum value of 91.4 dBA recorded at 20:07:25. Higher values may cause discomfort to the human body.

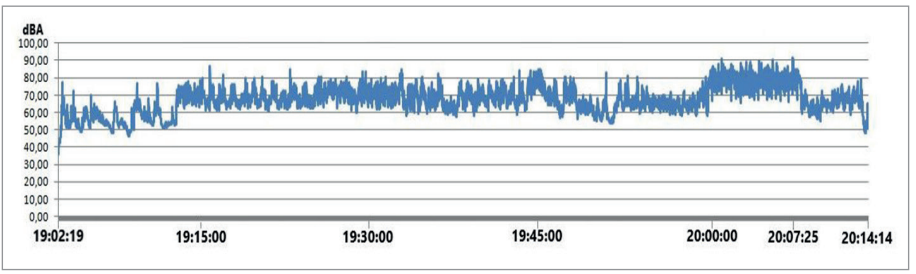

Fig. 8 Acoustic intensity level during the religious service on 08.08.2024, in the time interval 19:02:19 - 20:14:14

Visitors' perceptions of indoor air quality and its health effects

In the evaluation of factors that participants found bothersome within the space, the top three issues reported "often" or "very often" were dry air (45.5%), closed or unventilated air (36.7%), and dust (35.6%). These factors were the most frequently cited as causes of discomfort in the space. Conversely, the least reported issues included visible mould or apparent moisture (3.3%), odours from outside (6.7%), and indoor air temperatures that were too low (7.8%), indicating minimal concern regarding these factors among participants (Figure 9).

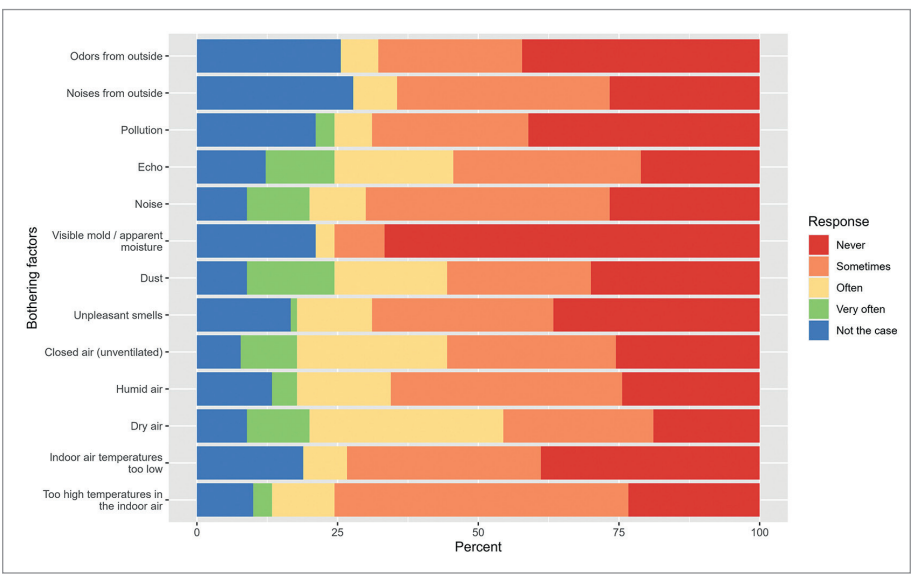

Fig. 9 The identified bothering factors in the church interior

The most frequently reported symptoms experienced "often" or "very often" were dry throat (21.1%), repeated sneezing (16.7%), and congestion of the nasal passages (14.4%). Conversely, the least reported symptoms were nausea or vomiting, dizziness or fainting, and headache and migraine.

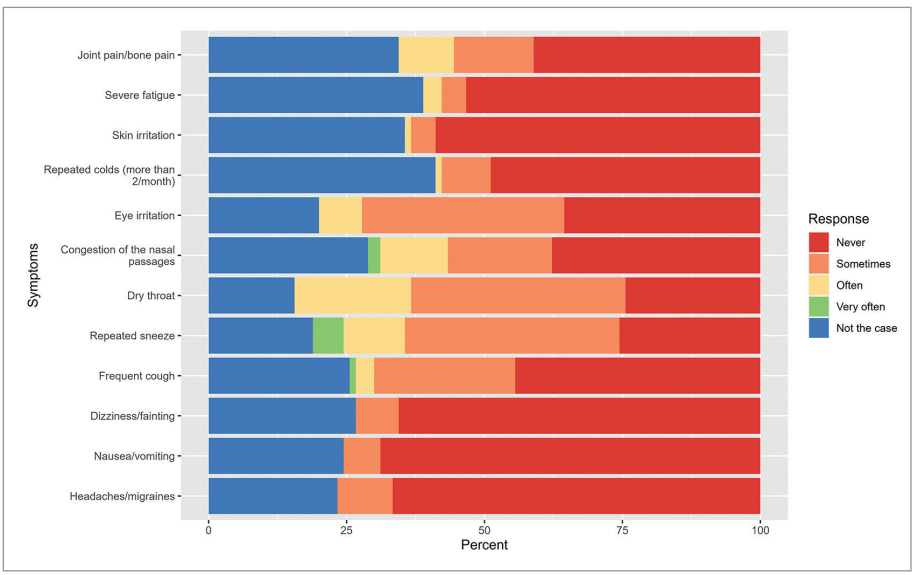

Fig. 10 The most frequently reported symptoms occurring in respondents during a visit to a church interior

Participants reported spending an average of 1.2 hours per day in the space, with religious activities being the primary reason for visitation (63.3%). The majority rated the air quality within the space as "Good" (64.4%), while a small portion rated it as "Low" (13.3%, see Figure 3). In cases where air quality issues were observed, 22.2% noted that they were most prominent at the end of activities. Most participants (72.2%) indicated that symptoms related to air quality resolved within 1-2 hours after leaving the space, and only 4.4% were aware of any complaints about the space's air quality. Among participants aware of complaints related to the space (n=4), reports of inconvenience were equally attributed to occasional visitors or users (50.0%) and individuals from the neighbourhood (50.0%). When describing the ideal environment, participants emphasized emotional and spiritual benefits, with equal mentions (25.0% each) of finding peace through prayer, experiencing a beautiful and recommended location, achieving personal peace in a relationship with God, and feeling an intensified divine presence that strengthens religious convictions (see Table 3).

Table 3 Respondents' perception of the monument space

		Smokers (%)	Taking medication regularly (%)	With chronic illness or allergies (%)	Total (%)
What is the main motive of your visit?	Religion	92.3	83.7	68.3	63.30
	Tourism and religion	0.0	7.0	9.0	25.60
	Tourism	0.0	0.0	0.0	2.20
	Rituals and traditions	0.0	4.7	13.7	4.40
	Festivals and religious holidays	7.7	2.3	4.5	2.30
	Charitable activities	0.0	2.3	4.5	1.10
	Research	0.0	0.0	0.0	1.10
In general, how do you rate the air quality in this space?	Very low	0.0	0.0	0.0	0.0
	Low	30.8	11.6	18.2	13.3
	Good	38.5	62.8	50.0	64.4
	Very good	23.1	20.9	22.7	12.2
	I don't answer	7.7	4.7	9.1	10.0
If you have noticed air quality problems in this space, when do you think they are most pronounced?	At the beginning of the activity	0.0	0.0	0.0	0.0
	During the activity	30.8	9.3	4.5	12.2
	At the end of the activity	30.8	7.0	27.3	22.2
	All the time	0.0	7.0	13.6	5.6
	Not applicable	38.5	67.4	50.0	51.1
	I don't answer	0.0	9.3	4.5	8.9
Do most of the mentioned symptoms disappear within a maximum of 1-2 hours after leaving this space?	Yes	76.9	76.7	68.2	72.2
	No	0.0	0.0	0.0	0.0
	Not the case	23.1	23.3	31.8	27.8
Are you aware of any complaints about inconvenience caused by the use of this space?	Yes, I am aware of many complaints	0.0	0.0	0.0	0.0
	Yes, I have heard of some complaints	0.0	0.0	4.5	4.4
	No, I have not heard of complaints	53.8	76.7	68.2	48.9
	I don't know	46.2	23.3	27.3	46.7
If you are aware of complaints, which group(s) reported inconvenience?	Occasional visitors/users	50.0	50.0	100.0	50.0
	Neighborhood	50.0	50.0	0.0	50.0

		Smokers (%)	Taking medication regularly (%)	With chronic illness or allergies (%)	Total (%)
The ideal environment. Can you describe this location?	A place with a great emotional charge, here you find the peace you need in your conversation with God, through the voice of prayer	0.0	33.3	33.3	25.0
	It is a beautiful location and I recommend visiting it	0.0	0.0	0.0	25.0
	It is the ideal place that gives you peace of mind in your personal relationship with God	0.0	33.3	33.3	25.0
	It is the ideal place where you feel the divine presence everywhere, your religious convictions are accentuated more strongly	100.0	33.3	33.3	25.0

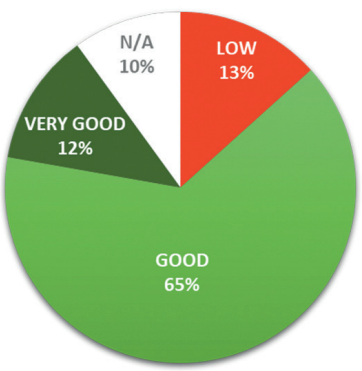

Fig. 11 Perceived indoor air quality according to respondents

Individuals without diagnosed health problems were more likely to report increased bothering factors in the space (beta = 3.54, 95% CI, 1.11 to 5.97, p = 0.005). Commute times of 31-60 minutes were also associated with increased bothering factors (beta = 3.19, 95% CI, 1.05 to 5.33, p = 0.004). Additionally, participants exposed to extreme temperatures rarely (beta = 5.22, 95% CI, 1.92 to 8.52, p = 0.003), occasionally (beta = 3.99, 95% CI, 0.66 to 7.32, p = 0.021), or frequently (beta = 6.71, 95% CI, 2.26 to 11.2, p = 0.004) in their daily activities were significantly more likely to report increased bothering factors (Table 4).

Table 4 Independent predictors of reporting increased bothering factors in the space

		Beta	95% CI	p-value
Diagnosed with health problems (chronic diseases, allergies)	Yes	Reference	Reference	
	No	3.54	1.11, 5.97	0.005
On average, how long does the trip take one way to this space?	Less than 15 minutes	Reference	Reference	
	31-60 minutes	3.19	1.05, 5.33	0.004
How often are you exposed to extreme temperatures in your daily activities?	Never	Reference	Reference	
	Rarely (less than once a month)	5.22	1.92, 8.52	0.003
	Occasionally (1-3 times a month)	3.99	0.66, 7.32	0.021
	Frequent (1-3 times a week)	6.71	2.26, 11.2	0.004

CI = Confidence Interval;
Results are based on a backward step-wise, multivariable generalized linear model

Participants not currently receiving medication reported fewer symptoms (beta = -1.70, 95% CI, -2.92 to -0.48, p = 0.008). Experiencing poor air quality during commutes was significantly associated with increased symptoms, particularly among those who experienced it rarely (beta = 2.58, 95% CI, 0.87 to 4.28, p = 0.004), sometimes (beta = 3.49, 95% CI, 1.72 to 5.26, p < 0.001), or often (beta = 5.36, 95% CI, 1.73 to 8.99, p = 0.005, Table 5). Our analysis shows that the number of symptoms reported by respondents was related to different variables. Based on the above results, the null hypothesis ($H2_0$) was rejected.

Table 5 Perceptions of air quality in relation to independent predictors of the symptoms described

		Beta	95% CI	p-value
Currently receive medication (daily/weekly/monthly)	Yes	Reference	Reference	
	No	-1.70	-2.92, -0.48	0.008
How often do you experience poor air quality during your commute?	Never	Reference	Reference	
	Rarely	2.58	0.87, 4.28	0.004
	Sometimes	3.49	1.72, 5.26	<0.001
	Often	5.36	1.73, 8.99	0.005

CI = Confidence Interval;
Results are based on a backward step-wise, multivariable generalized linear model

CONCLUSIONS

The conservation of heritage objects, including valuable wooden churches, is important because over the years, they are prone to deterioration (Ilies et al., 2018), and their physical protection is essential, due to the historical, and artistic values and artefacts in their space (Uring et al., 2020; Ginting et al., 2024). Within historical monuments, the indoor microclimate is an important factor that affects buildings and exhibits and has an influence on people's health (Horgos et al., 2023; Zaha et. al., 2023). On the other hand, parishioners or visitors to historical monuments can themselves be a source of influence on the indoor microclimate (Ferdyn-Grygierek, 2016).

The construction material plays an important role, as wood facilitates the presence of microbial loads (Stenson et al., 2019). An important role that can facilitate the appearance of pollutants is represented by the defective construction of buildings (Bungau et al., 2023). Studies have confirmed that both suspended particles and dust are extremely dangerous to human health (Kim et al., 2015; Nonthapot et al., 2024). High concentrations of formaldehyde, total volatile organic compounds, can pose a risk to people by causing nausea, and dizziness, with the potential to cause asthma and in some cases even cancer (Baroja et al., 2005).

The above conclusions were confirmed by the research presented in this study. According to the data obtained, it is concluded that the air inside the church represents a risk factor not only for the objects inside but also for human health. The temperature range recorded inside the church did not meet international standards over the one-year monitoring period, with an average of 11.69°C, having large fluctuations between a minimum of -6.4°C and a maximum of 29°C. The relative humidity in a one-year period had high values with an average of 70.83%, which poses a risk to the degradation of bio-materials in the building (including the constructional wooden parts, carpets, and textiles), and for human health. High levels of PM2.5, PM10, and VOC have occasionally been noted in different periods, influencing the indoor microclimate, which can cause respiratory and olfactory problems, irritation, fatigue and headaches. The results of the survey conducted on a sample of 90 visitors reveal that the respondents' main negative perceptions were dry air (45%), closed, unventilated air (36.7%) and dust (35.6%). The most common health symptoms exhibited in the space were dry throat (21.1%), repeated sneezing (16.7%) and nasal congestion (14.4%). Two hypotheses were tested using multivariate generalized linear models. The null hypotheses were both rejected, indicating that the characteristics of individuals influenced the perceptions of bothering factors and the experienced symptoms. This highlights the fact that the microclimatic conditions inside the church did impact the health and comfort of visitors.

Primary on-site research identified obvious significant damage to some of the interior features. The wooden church has some damaged windows, a result

of the internal microclimate parameters which are influenced by the external climate. The devices needed to be connected to the power supply at all times and during periods of power outages, external batteries were used. To reduce airborne particulate matter and the degradability of the interior wood elements, as well as to reduce the risk of health damage and increase the comfort of visitors, we recommend the installation of an HVAC system and the use of air filters throughout the interior of the protected building. Cleaning is recommended to eliminate dust, which supports the development of microorganisms together with high humidity. For cold weather, the installation of a heating system is advisable. The removal of carpets, textiles, and rugs, which harbour dust, will assist in reducing this factor.

Future studies are required to complete the research with further monitoring of other pollutants such as O2, O3, SO2, CH4, NO, NO2, H2S, CO, microbiological investigations and their influence on the inside artefacts and human health. The respondents also reported the sound system inside the church as problematic, which they described as an element that reduced the quality of the experience. Our measurements confirmed these claims. It showed that the recorded values fluctuated significantly during events and services, varying from 35.7 dBA to a maximum of 91.4 dBA. Higher values can cause discomfort to the human body. For this reason, we recommend tuning the loudspeakers so that the acoustics do not cause discomfort and disturbance to the human body and do not reduce the quality of the experience for visitors.

To prevent the degradation of historical monuments, preventive conservation is needed, therefore the conditions of the indoor environment must be monitored and evaluated, and they must be maintained at the requisite level of standards. Temperature and humidity are two air variables with an important impact on the deterioration of the inside artefacts, and the health of visitors and parishioners (Ilies et al., 2019). In addition to these two air variables, less or more light has consequences for the building and the artefacts and must be carefully monitored (Ferdyn-Grygierek, 2016), this being one of the greatest threats to the integrity of the exhibits.

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