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Organisational resilience as a determinant of the development of innovative service enterprises

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ABSTRACT
The article aims to diagnose the relationship between the formation of organisational resilience and the development of innovative service enterprises. The leading approach of the study was inductive. It also used analysis and synthesis methods. The leading empirical method was a diagnostic survey in the form of a CAWI survey. The statistical analysis was used for quantitative data. The research tools used included the CAWI survey questionnaire, PS IMAGO PRO 10.0, and MS Excel software. The empirical study was conducted on a sample of 100 respondents representing companies classified into the following PKD sections, which belong to the sub-sector of high-tech knowledge-intensive services: 59, 60, 61, 62, 63, and 72. Proportional stratified sampling was used, and the numbering of PKD departments determined the strata.The survey showed the importance of shaping organisational resilience for developing service enterprises in the following areas: process and product, financial, and market at a moderate level. In addition, positive correlations of moderate strength were identified between the importance of shaping organisational resilience in the financial area and the importance of shaping organisational resilience in the process and product area, and the market area. What is more, no statistically significant differences were found in the importance of shaping resilience for the development of service enterprises in the following areas: process and product, financial and market between different classes of these enterprises distinguished according to the following criteria: leading business profile, age, scale of operations, and average annual turnover. The issue of shaping organisational resilience should be developed in the activity of innovative entities. Shaping resilience can positively impact enterprises' development and position in the market. Managers and/or business owners must identify the principal areas of resilience development, and the leading effects associated with its development, which will enable/improve the estimation of the level of development of a given company.

KEY WORDS
organisational resilience, innovative enterprise

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Introduction

Organisational resilience is often defined as an organisation's ability to cope with adversity (Weick, 2016). Crisis phenomena caused, among others, by the COVID-19 pandemic, the war in Ukraine, or climate change mean that organisational resilience is indicated as an essential and current subject of research, including research in the discipline of management and quality sciences (Ingram, 2023; Williams et al., 2021; Clement & Rivera, 2017). The indicated adverse social, economic, and natural phenomena cause enterprises, including service enter-

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prises, to operate in conditions of far-reaching unpredictability of the environment and, thus, in conditions of uncertainty. Hence, the increased interest in the concept of organisational resilience, i.e., the search for mechanisms and processes that will allow organisations to function and even develop despite such difficult operating conditions, has been observed in recent years (Marquez-Tejon et al., 2024; Verreynne et al., 2018; Vetrova et al., 2020). The article discusses the resilience of service enterprises, treating them as specific economic entities requiring a separate research approach. In the case of service enterprises, which most often belong to the group of SMEs, individual resilience plays a unique role in shaping organisational resilience because the person of the owner and the manager are usually the same. The organisation's survival in the face of crisis may depend on the behaviour of this crucial player from the organisation's perspective (Soluk et al., 2021).

Previous research (van der Vegt et al., 2015; Song, 2022; Ingram, 2023) indicates that organisational resilience may depend on several different factors that can determine the survival of a given innovative entity, e.g., human, financial, knowledge, and material resources (Ngoc Su et al., 2021; Webb & Chaffer, 2016; Searing et al., 2021; Polyanska et al., 2019). Innovative enterprises must develop each of these areas. In innovation processes, there must be no "gaps" and "bottlenecks" that reduce the level of organisational resilience because this will probably harm the value provided to the stakeholders of these processes. The research conducted so far on shaping the resilience of enterprises (including innovative ones) has a limited subject scope and focuses on individual resources (Chang, 2021; Wieczorek-Kosmala, 2022), processes (Stoverink et al., 2020) in enterprises or the scale of their operations (Möller et al., 2018; Hundal et al., 2021). Therefore, a "gap" lacks an extensive holistic empirical view. The study conducted by the authors of this article fills this "gap". It can be the basis for more complex and comprehensive conclusions on applying mechanisms for shaping organisational resilience in developing innovative service enterprises. In addition, the study focuses on the importance of shaping organisational resilience for developing service enterprises in three areas: process and product, financial, and market.

The article aims to diagnose the relationship between organisational resilience formation and the development of innovative service enterprises. The following research problem was raised: What is the importance of shaping organisational resilience for developing innovative service enterprises? A diagnostic survey in the form of a CAWI survey was used to solve the indicated problem. In addition, statistical analysis of quantitative data was used. The empirical study was conducted on 100 respondents representing companies classified as the sub-sector of high-tech knowledge-intensive services.

The article consists of five main parts: (1) "Literature review" presenting the essence of the phenomenon of organisational resilience and its importance in the context of the activities of innovative enterprises; (2) "Research methods", with particular emphasis on the research problem and research hypotheses, specification of the scope of research and research methods used, as well as the structure of the research sample; (3) "Research results" in the perspective of the three areas where the primary effects of shaping resilience can be observed: process and product, financial and market; (4) "Discussion of the results", comparing the results obtained with the researches of other authors; and (5) "Conclusions", containing recommendations for the practice of management.

1. Literature review

Research on organisational resilience undertaken in management and quality sciences has a long history (Hillmann & Guenther, 2021; Ingram, 2023). However, no single, universally accepted definition of the concept exists (van der Vegt et al., 2015; Kossek & Perrigino, 2016; Kahn et al., 2018; Ingram & Głód, 2018; Buyl et al., 2019; Olekalns et al., 2020; Stoverink et al., 2020). The concept of organisational resilience was introduced into the literature by Mallak (1998). In his concept, resilience is built on constructive perception of experiences and positive adaptive behaviours. It is associated with providing adequate resources, expanding decision-making boundaries, and developing the ability to create solutions immediately using available resources (Ingram, 2023). It is most often assumed that organisational resilience is a set of adaptation mechanisms based on the competencies (capabilities) of the company that affect the possibilities of organisational renewal after a crisis (Ingram, 2023). Duchek (2020) pointed out that immunity is a specific ability to respond to unforeseen random events. Resilience is also treated as one of the possible responses of a company to a crisis (Kowalewski & Moczydłowska, 2024), along with antifragility or robustness and sustainability (Munoz et al., 2022). Organisational resilience is, therefore,

one of the types of resilience characteristic of the organisation's entity. It is essential because it is a condition for maintaining sustainable organisational effectiveness (Yu & Zhu, 2022) and, in challenging situations, a condition for survival.

Organisational resilience research focuses on diverse sources of potential threats. These sources can be external, such as natural disasters, political turmoil and war (Zhou et al., 2022), and internal, such as corruption (Tunley et al., 2018). Organisational resilience is primarily intended to respond to rapid changes in the company's environment (Jiang et al., 2019), uncertainty (Burnard & Bhamra, 2011), and complexity (Kagan & Kirchberg, 2016). Resilience is identified with organisational adaptation or is supposed to lead to adaptation to rapid changes in the environment (Wissman-Weber & Levy, 2018). In addition to the critical adaptation process, it also includes the pursuit of responsibility and sustainability in action (Stone & Rahimifard, 2018; Visser, 2021; Song, 2022), making sense (Teo et al., 2017; Tisch & Galbreath, 2018), balancing organisational structures (Andersson et al., 2019), planning (Weigand et al., 2014), collective organisational mindfulness (Wang et al., 2021), employee empowerment (van den Berg et al., 2022), use of organisational routines (Manfield & Newey, 2018; Jiang et al., 2019; Ingram, 2023).

The analysis of organisational resilience also requires establishing the relationship between the concept of resilience and risk management. Risk management, which has a comprehensive theoretical foundation, is one of the concepts related to organisational resilience, as it can be assumed that it is one of the mechanisms supporting the survival of an organisation (Douglas & Haley, 2024). Thus, it has functions like immunity (van der Vegt et al., 2015). Risk management attempts to prepare an organisation for unforeseen events (Andersson et al., 2019).

The resource-based approach dominates research on organisational resilience sources (Wieczorek-Kosmala, 2022). The role of human resources is crucial here first and foremost (Ngoc Su et al., 2021), and only secondarily, financial and information (technological) resources. Organisational resilience is determined by the ability to minimise employee competency gaps (Webb & Chaffer, 2016), the professionalism of HR policies and the flexibility of HR solutions (Chung, 2022), and the sense of job security among employees (Filimonau & de Coteau, 2020). A significant source of resilience is free financial resources, the so-called slack resources (Leuridan & Demil, 2022), and financial resources in general (Searing et al., 2021). There is no doubt that financial resources facilitate the adaptation to new conditions significantly, which is crucial from the perspective of the company's survival through the possibility of introducing new solutions responding to new market conditions (Ingram, 2023). The individual characteristics of individuals: owners, managers, and critical decision-makers also play a crucial role in shaping organisational resilience (Anwar et al., 2023). The most frequently indicated individual determinants of resilience are self-efficacy (Alonso et al., 2019), personal mental resilience of the leader and coping with stress (Stoverink et al., 2020), absence of narcissistic tendencies and excessive risk-taking (Buyl et al., 2019).

Analysing scientific achievements on organisational resilience justifies asking about the universality of methods and techniques constituting organisational resilience. Many recommendations, including those on immunity, are universal (Monazzam & Crawford, 2024). Organisational learning and knowledge management, mature leadership, having action plans in crises, flexible shaping of resources, especially human, development of relational capital, etc., are indicated (Saad et al., 2021). However, some of the suggestions are highly specific to the context in which resilience is analysed, e.g., resulting from the location of the subjects studied (Möller et al., 2018; Ingram, 2023), their size, or the specifics of their business (Hundal et al., 2021).

The critical issue in this article's topic is the relationship between organisational resilience and innovation. Most researchers treat innovation as a source of resilience (Senbeto & Hon, 2020; Huang & Jahromi, 2021; Do et al., 2022), although there are also publications in which this relationship is reversed, i.e., innovation is indicated as a result of organisational resilience (Santoro et al., 2020; Akgün & Keskina, 2014).

To sum up the epistemological analysis, it should be stated that there are two dominant views on the essence of the activities of organisations describing the mechanisms of immunity. Some researchers assume that it is a passive adaptive ability, and then the focus is on adaptation processes (Ali & Gölgeci, 2019). In this approach, resilience leads to survival. In the second approach, which is closer to the authors of this article, developmental change is an expression of resilience (Prayag et al., 2020). Resilience assumes not only passive adaptation or change in the face of disruption but also that the ability to predict and effectively counteract potential turbulence in the environment is dormant (Duchek, 2020).

2. Research methods

The subject of the study was the perception of organisational resilience as a factor stimulating the development of enterprises in Poland. The study's main objective was to estimate the importance of shaping organisational resilience as a determinant of the development of innovative service enterprises. The research refers to the respondents' ratings and opinions. The research problem was formulated: What is the importance of shaping organisational resilience for developing innovative service enterprises? The study put forward the following hypotheses:

[H-1] The importance of shaping organisational resilience is high for developing service enterprises in the following areas: process and product, financial, and market.

[H-2] a) A strong positive correlation exists between the importance of shaping organisational resilience in the financial area and the importance of shaping organisational resilience in the process and product area. b) A strong positive correlation exists between the importance of shaping organisational resilience in the financial area and the importance of shaping organisational resilience in the market area.

[H-3] a) Statistically significant differences exist in the importance of shaping resilience for the development of service enterprises in the following areas: process and product, financial and market between different classes of these enterprises distinguished according to the criterion of the leading business profile. b) Statistically significant differences exist in the importance of shaping resilience for developing service enterprises in the following areas: process and product, financial and market, between different classes of these enterprises, as distinguished by age. c) Statistically significant differences exist in the importance of shaping resilience for the development of service enterprises in the following areas: process and product, financial and market, between different classes of these enterprises, which are distinguished according to the criterion of the scale of operation. d) Statistically significant differences exist in the importance of shaping resilience for the development of service enterprises in the following areas: process and product, financial and market, between different classes of these enterprises, which are distinguished according to the average annual level of turnover criterion.

The study's objective, subjective, spatial, and temporal scope was determined (Table 1). The study used an inductive approach. Elements of the deductive approach were also included, but the inductive approach played the leading role in the study. Analysis and synthesis were also used in the study. The leading empirical method was a diagnostic survey (Karbownik, 2017) in the form of a CAWI (Computer-Assisted Web Interview) survey. A statistical analysis of quantitative data was also used. In addition, the following research tools were used:

- CAWI questionnaire, which included a metric — five questions, the central part — 12 detailed questions requiring respondents to assess them on a 5-point scale (the value "1" meant very little importance of the impact of shaping organisational resilience on a given outcome, and the value "5" — very high importance) and one screening question,
- PS IMAGO PRO 10.0 and MS Excel software (for calculating descriptive statistics, performing Kolmogorov-Smirnov and Kruskal-Wallis tests for independent samples, determining Spearman's rho correlation and performing cluster analysis — k-means method, as well as sketching graphs).

In terms of the structure of the research sample, it should be noted that the respondents represented enterprises classified to the following PKD departments, which belong to high-tech sectors, and more specifically, to the sub-sector of high-tech knowledge-intensive services (Centrum Rozwoju Regionalnego w Braniewie, 2021; PKD, 2021). These are:

- department No. 59 — activities related to producing films, video recordings, television programmes, and sound and music recordings; department No. 60 — broadcasting of public and subscription programmes;
- department No. 61 — telecommunications;
- department No. 62 — software and IT consulting and related activities;
- department No. 63 — information service activities;
- department No. 72 — research and development.

20 % of respondents were in each of these layers (Fig. 1). On the other hand, considering the age parameter, the sample was dominated by young entities, i.e., operating on the market for up to five years (32 %) and relatively young, i.e., operating on the market for 6–10 years (31 %). The smallest percentage of enterprises in the sample were mature, i.e., entities operating for 11–15 years (14 %) (Fig. 2).

Tab. 1. Scope of the empirical study

Scope	Description
Objective scope	Perception of the development of organisational resilience as a determinant of the development of innovative service enterprises.
Subjective scope	The survey was conducted on a random sample (proportional stratified sampling — the numbering of PKD sections determined the strata) of business owners or managers responsible for risk management, innovation processes, or project management (one respondent from each surveyed company). The study included companies from the *high-tech, knowledge-intensive services sector*. The research sample consisted of 100 organisations (micro, small, and medium-sized entities based in Poland and conducting their activities mainly in Poland). Eligible for the study were people who answered "yes" to the screening question: *Has your company completely and correctly implemented at least five product and/or process innovations in the last five years of its operation on the market, and does the company share resources with other participants in innovation processes?*
Spatial scope	The study covered almost the entire Polish region — the surveyed companies were located in 13 voivodeships.
Temporal scope	The survey was conducted from July to August 2021 and covered the last five years of business activity, i.e., January 2016 to December 2020.

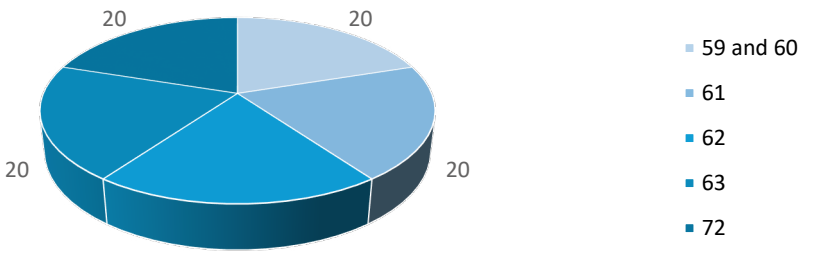

Fig. 1. Leading business profile (according to PKD) of the surveyed service companies [%] (N=100)

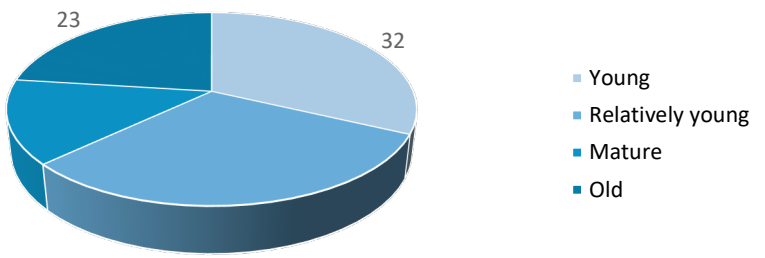

Fig. 2. Age of the surveyed service enterprises [%] (N=100)

Considering the criterion of the scale of action, it can be assumed that the research sample was dominated by entities operating on a local scale (1 city/commune/district) — 36 % and on a regional scale (1–8 voivodeships in Poland) — 24 %. A smaller percentage of the surveyed entities conduct processes on the following scales: national (9–16 voivodeships in Poland) — 19 %, European (at least one country in Europe outside Poland) — 14 %, and international (at least one country in the world outside Europe, including Poland) — 7 %. In addition, the research sample was dominated by entities that achieved an average annual turnover level of PLN 0–0.5 million — 34 % and PLN 0.5– 1 million — 24 %. Annual turnover

values of companies were as follows: PLN 1–1.5 million — 16 %, PLN 1.5–2 million — 7 %, PLN 2 – 2.5 million — 3 %, PLN 2.5–3 million — 4 %, and more than PLN 3 million — 12 %.

The spatial distribution of the surveyed service enterprises was diverse. The research sample was dominated by entities from the following voivodeships: Śląskie (18 %) and Mazowieckie (17 %), as well as Pomorskie (12 %), Dolnośląskie (10 %), and Wielkopolskie (10 %).

The above contents allow assuming that the research sample was diverse. However, it should be noted that the study's authors are aware that the sample is not representative, and it is impossible to conclude the population based on it. Nonetheless, the authors believe that the study may become the basis for identifying general trends and formulating basic guidelines and recommendations for perceiving organisational resilience as a determinant of the development of service enterprises.

3. Research results

Considerations on the perception of organisational resilience as a determinant of the development of innovative service enterprises should begin with an indication of the areas where the primary effects of shaping resilience can be observed. The study assumes the following three areas: process and product, financial, and market (Table 2). Such a division was adopted mainly because it exposes the basic classes of effects related to the development of innovative service enterprises and focuses both on the perspective

Tab. 2. Basic areas of shaping resilience and impact on the development of enterprises

Area	Basic effects of resilience
Process and product	• Reducing employee errors.Increasing the number of innovations/new solutions/products/services developed. • Increasing the volume of sales of products/services. • Reducing the time needed to plan and prepare business processes. • Reducing the time to develop innovations/new solutions/products/services.
Financial	• Effective and planned implementation of the company's budget assumptions. • Increasing the company's financial liquidity. • Reducing the total cost of the company. • Increasing profits.
Market	• Increasing the level of specialisation of the activity on the market. • Increasing the company's market share. • Increase in customer numbers.

Tab. 3. Descriptive statistics for the importance of shaping organisational resilience for the development of service enterprises — process and product area (N=100)

Statistics	Effects of shaping resilience				
	Reducing employee errors	Increasing the number of innovations/new solutions/ products/services developed	Increasing the volume of sales of products/ services	Reducing the time needed to plan and prepare business processes	Reducing the time to develop innovations/ new solutions/ products/ services
Mean	3.40	2.93	3.47	3.23	3.18
Median	3.00	3.00	4.00	3.00	3.00
Dominant	3	3	3	3	3
Standard deviation	1.239	1.103	1.185	1.043	1.114
Variance	1.535	1.217	1.403	1.088	1.240
Skewness	-0.319	0.095	-0.578	-0.150	-0.275
Kurtosis	-0.664	-0.566	-0.262	-0.067	-0.353
Range	4	4	4	4	4
Minimum	1	1	1	1	1
Maximum	5	5	5	5	5

of innovative activity and aspects of the market environment and financial potential. Therefore, it can be assumed that this perspective considers three main pillars of developing innovative entities. Of course, the authors know this is one of many classifications, but the abovementioned areas were adopted for the study.

The first of the issues considered is the importance of shaping organisational resilience for developing service enterprises in the following areas: process and product, financial and market. Considering the first area — process and product — it can be noted that in the opinion of the respondents (the respondents assessed each effect of shaping resilience using a 5-point scale, where the value "1" meant very little importance of the impact of shaping organisational resilience on a given effect, and the value "5" — very high importance) the most significant importance of shaping resilience is in terms of effects: increasing the volume of sales of products/services (average score at the level of 3.47) and reducing the number of errors made by employees (average rating at the level of 3.40). On the other hand, the least important is the increase in the number of developed innovations/new solutions/products/services (average score at the level of 2.93) (Table 3).

Considering the next area — financial, — it can be noted that in the opinion of the respondents, the most significant importance of the impact of shaping organisational resilience is for the effects in the following areas: increasing profits (average rating at the level of 3.74), increasing the financial liquidity of the

Tab. 4. Descriptive statistics for the importance of shaping organisational resilience for the development of service enterprises — financial area (N=100)

Statistics	Effects of shaping resilience			
	Effective and planned implementation of the company's budget assumptions	Increasing the company's financial liquidity	Reducing the total cost of the company	Increasing profits
Mean	3.53	3.61	3.34	3.74
Median	3.50	4.00	3.00	4.00
Dominant	3	5	4	5
Standard deviation	1.132	1.246	1.312	1.186
Variance	1.282	1.553	1.722	1.406
Skewness	-0.523	-0.528	-0.300	-0.702
Kurtosis	-0.080	-0.622	-1.022	-0.321
Range	4	4	4	4
Minimum	1	1	1	1
Maximum	5	5	5	5

Tab. 5. Descriptive statistics for the importance of shaping organisational resilience for the development of service enterprises — market area (N=100)

Statistics	Effects of shaping resilience		
	Increasing the level of specialisation of the activity on the market	Increasing the company's market share	Increase in customer numbers
Mean	3.40	3.56	3.92
Median	3.00	4.00	4.00
Dominant	3	3	5
Standard deviation	1.137	1.192	1.107
Variance	1.293	1.421	1.226
Skewness	-0.421	-0.583	-0.933
Kurtosis	-0.355	-0.263	0.207
Range	4	4	4
Minimum	1	1	1
Maximum	5	5	5

company (average rating at the level of 3.61) and effective and planned implementation of the company's budget assumptions (average rating at the level of 3.53). It is crucial for the effect related to the reduction of total costs of business activity (average rating at the level of 3.34) (Table 4).

On the other hand, in the respondents' opinion, the last of the specified areas — the market area — is characterised by the most significant importance of shaping resilience for increasing the number of customers (average score at 3.92). For this area, the effect related to increasing the level of activity specialisation on the market is of relatively minor importance (average score at 3.40) (Table 5).

Mean values were determined (using arithmetic mean statistics) for the effects of resilience development in each of the three areas. On this basis, it was possible to determine the average importance of shaping organisational resilience for developing service enterprises in process and product, financial, and market areas (Table 6).

The analysis of the importance of shaping organisational resilience for developing service enterprises in process and product, financial, and market areas referred to a 5-point scale. The following assessment levels were adopted in the study:

- Low — average grade values in the range 1–2.33).
- Moderate — average grade values in the range 2.33–3.66).
- High — average grade values in the range 3.66–5.

The authors are aware of the fact that this is a contractual division into three "equal" areas of assessment and, in fact, the evaluation of the importance of shaping organisational resilience for the development of service enterprises in process and product, financial and market areas in each business entity can be considered differently, considering different limit values and criteria. Referring to the established ranges, it can be noted that the average importance of shaping organisational resilience for the development of service enterprises in the following areas: process and product, financial and market

Tab. 6. Descriptive statistics for the importance of shaping organisational resilience for the development of service enterprises — the perspective of three areas (N=100)

Statistics	Areas		
	Process and product	Financial	Market
Mean	3.24	3.56	3.63
Median	3.20	3.63	3.67
Dominant	3.00	3.00	3.67
Standard deviation	0.704	0.753	0.825
Variance	0.496	0.566	0.681
Skewness	0.031	-0.420	-0.475
Kurtosis	1.242	0.929	0.486
Range	4.00	4.00	4.00
Minimum	1.00	1.00	1.00
Maximum	5.00	5.00	5.00

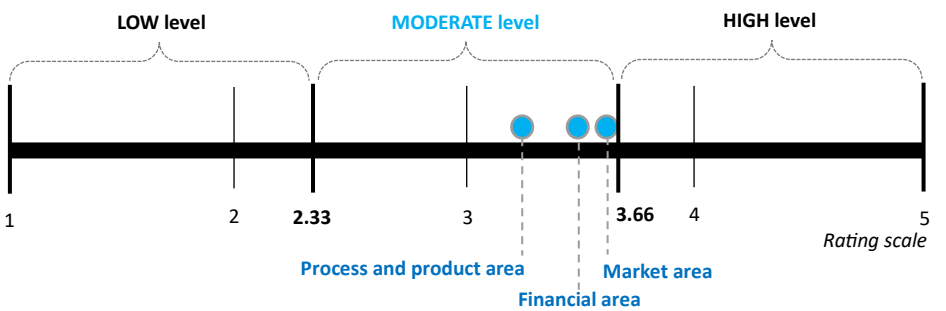

Fig. 3. Average ratings for the importance of shaping resilience in three areas (process and product, financial, and market) for the development of service enterprises (N=100)

is at a moderate level (Fig. 3). Therefore, based on the above results, it is possible to falsify the hypothesis [H-1] in the following wording: The importance of shaping organisational resilience is high for developing service enterprises in the following areas: process and product, financial, and market.

At this point, it is also worth referring to the identification and analysis of the structure of clusters of the surveyed service enterprises in terms of average assessments of the importance of shaping organisational resilience for their development in the following areas: process and product, financial, and market. It can be noted that the research sample is dominated by entities with moderate ratings of importance in all three areas (58 %). A significant percentage (40 %) are also companies with high ratings of the importance of shaping organisational resilience for their development in all three areas (Table 7).

Reference should be made to Spearman's rho coefficient, among other things, assessing potential correlations between the importance of shaping organisational resilience in the financial area and the importance of shaping organisational resilience in the process and product, and market areas because the variables describing the importance of shaping organisational resilience in each of the three areas do not have a normal distribution (Table 8). The correlation coefficient between the importance of shaping organisational resilience in the financial area and the importance of shaping organisational resilience in the process and product area is 0.331, and between the importance of shaping organisational resilience in the financial area and the importance of shaping organisational resilience in the market area is 0.422. The correlation is positive in both cases, but its strength is moderate/weak (Table 9).

Based on the above results, it is possible to falsify the hypotheses:

- [H-2a] as follows: A strong positive correlation exists between the importance of shaping organisational resilience in the financial area and the importance of shaping organisational resilience in the process and product area.

Tab. 7. Clusters of enterprises due to average assessments of the importance of shaping organisational resilience for the development of service enterprises in the following areas: process and product, financial, and market (N=100)

	Cluster		
	No. 1	No. 2	No. 3
	Enterprises with moderate ratings of importance in all three areas	Enterprises with low ratings of importance in all three areas	Enterprises with high ratings of importance in all three areas
Stand: Process and product area	-0.24090	-2,75859	0.48723
Stand: Financial area	-0.46827	-3,06276	0.83213
Stand: Market area	-0.42517	-2,98152	0.76558
N (%)	58 (58)	2 (2)	40 (40)

Tab. 8. Kolmogorov-Smirnov test for one sample — testing the normality of distribution for variables describing three areas of impact of resilience on the development of service enterprises (N=100)

H0	Significance[a]	Decision
The variable "process and product area" distribution is normal, with a mean of 3.24 and a standard deviation of 0.70398.	0.008	Reject the H0 hypothesis
The variable "financial area" distribution is normal, with a mean of 3.56 and a standard deviation of 0.75259.	0.011	
The variable "market area" distribution is normal, with a mean of 3.63 and a standard deviation of 0.82508.	<0.001	

a. Significance level is 0.050.
Lilliefors' method is based on Monte Carlo (10000) samples with an initial value of 624387340.

Tab. 9. Spearman's rho correlations between the importance of shaping organisational resilience in the financial area and the importance of shaping organisational resilience in the process and product and market areas (N=100)

		Process and product area	Market area
Financial area	Correlation coefficient	0.331*	0.422*
	Significance (two-sided)	<0.001	<0.001

* Correlation significant at 0.01 (two-sided).

Tab. 10. Kruskal-Wallis test for independent samples — the leading business profile criterion (N=100)

H0	Significance[a]	Decision
The distribution of the "process and product area" variable is the same for all "leading business profile" categories.	0.185	There are no grounds for rejecting the H0 hypothesis
The distribution of the "financial area" variable is the same for all "leading business profile" categories.	0.622	
The distribution of the "market area" variable is the same for all "leading business profile" categories.	0.253	

a. The significance level is 0.050.
b. Asymptotic significance is presented.

Tab. 11. Kruskal-Wallis test for independent samples — the age criterion (N=100)

H0	Significance[a]	Decision
The "process and product area" distribution is the same for all "age" categories.	0.357	There are no grounds for rejecting the H0 hypothesis
The distribution of the "financial area" variable is the same for all "age" categories.	0.815	
The distribution of the "market area" variable is the same for all "age" categories.	0.270	

a. The significance level is 0.050.
b. Asymptotic significance is presented.

Tab. 12. Kruskal-Wallis test for independent samples — the scale of action criterion (N=100)

H0	Significance[a]	Decision
The "process and product area" distribution is the same for all "scale of action" categories.	0.358	There are no grounds for rejecting the H0 hypothesis
The distribution of the "financial area" variable is the same for all "scale of action" categories.	0.869	
The distribution of the "market area" variable is the same for all "scale of action" categories.	0.936	

a. The significance level is 0.050.
b. Asymptotic significance is presented.

Tab. 13. Kruskal-Wallis test for independent samples — the average annual turnover criterion (N=100)

H0	Significance[a]	Decision
The "process and product area" distribution is the same for all "average annual turnover" categories.	0.741	There are no grounds for rejecting the H0 hypothesis
The distribution of the "financial area" variable is the same for all "average annual turnover" categories.	0.723	
The distribution of the "market area" variable is the same for all "average annual turnover" categories.	0.703	

a. The significance level is 0.050.
b. Asymptotic significance is presented.

- [H-2b] as follows: A strong positive correlation exists between the importance of shaping organisational resilience in the financial area and the importance of shaping organisational resilience in the market area.

The last issue considered is whether there are differences in the importance of shaping resilience for the development of service enterprises in the following areas: process and product, financial and market between different classes of these enterprises distinguished according to the following criteria: leading business profile, age, scale of operation, and average annual turnover. For this purpose, the Kruskal-Wallis test was used for independent samples (Tables 10, 11, 12, and 13).

The Kruskal-Wallis test for independent samples (Tables 10, 11, 12, and 13) indicated no sufficient grounds to conclude that service enterprises differed. Based on the above results, it is, therefore, possible to falsify the hypotheses:

- [H-3a] as follows: Statistically significant differences exist in the importance of shaping resilience for the development of service enterprises in the following areas: process and product,

financial and market between different classes of these enterprises distinguished according to the criterion of the leading business profile.

- [H-3b] as follows: Statistically significant differences exist in the importance of shaping resilience for developing service enterprises in the following areas: process and product, financial and market, between different classes of these enterprises, as distinguished by age.
- [H-3c] as follows: Statistically significant differences exist in the importance of shaping resilience for the development of service enterprises in the following areas: process and product, financial and market, between different classes of these enterprises, which are distinguished according to the criterion of the scale of operation.
- [H-3d] as follows: Statistically significant differences exist in the importance of shaping resilience for the development of service enterprises in the following areas: process and product, financial and market, between different classes of these enterprises, which are distinguished according to the average annual level of turnover criterion.

The results obtained will be discussed in the next part of the article.

4. Discussion of the results

Shaping organisational resilience is a complex and challenging task in the current environment of enterprises, including those operating in the service sector. This is due to high competition in the market (not only local but also global), limited access to high-quality resources (e.g., staff and managers), and the need to integrate risk management with short- and long-term planning. However, shaping an appropriate level of organisational resilience is important because it can increase the likelihood of correct and relatively safe development of enterprises. However, it is difficult to indicate what precisely the acceptable "level" of such "resilience" should be. One approach worth applying in management practice is to focus on the individual effects that resilience can "strengthen". This approach is an opportunity for a relatively simple development of a set of measures/indicators that can be used to shape organisational resilience. This issue has not been developed in this article but will be the subject of further research by the authors.

The survey showed the importance of shaping organisational resilience for developing service enterprises in the following areas: process and product, financial, and market, which are at a moderate level. This is consistent with, e.g., results of the research by Leuridan and Demil (2022) and Searing et al. (2021) in terms of financial outcomes, Jiang et al. (2019) and Kagan and Kirchberg (2016) in terms of market activities, and Stone and Rahimifard (2018) and Visser (2021) in terms of product and process business development. It can also be assumed that the results obtained lead to similar conclusions as the research by Santoro et al. (2020) and Akgün and Keskina (2014) that innovation and the development of innovative activities result from properly shaped organisational resilience. It is also worth noting that the research conducted was maintained in the convention adopted by Prayag et al. (2020) and Duchek (2020), which states that shaping resilience is aimed at developing enterprises, including those from the service sector. Moreover, organisational resilience makes it possible to effectively counteract potential turbulence in the environment. The study modified the analytical perspective of the authors cited above, exposing the process and product, market, and financial areas, which gave a slightly more detailed illustration of the respondents' opinions.

The research results are also consistent with the conclusions published by Douglas and Haley (2024) and Andersson et al. (2019) on the link between shaping resilience and risk management. It is necessary to consider, e.g., reducing the number of errors made by employees, shortening the time of planning and preparing business processes, effective and planned implementation of the company's budget assumptions, and reducing the total costs of business activity. It can be assumed that the actions of managers/owners in the areas mentioned above are the "foundation" of risk management and constitute an attempt by innovative service companies to prepare for unforeseen events.

In addition, it is worth noting that the study showed positive correlations of moderate strength between the importance of shaping organisational resilience in the financial area and the importance of shaping organisational resilience in the process, product, and market areas. Therefore, it can be concluded, in a somewhat "cautious" way, that the increase in the importance of financial resilience, in a sense, corresponds to the rise in the importance of resilience for the company's operations on the market

and the development of its core business (innovative in the process and product range).

At this point, it is also worth noting that there are no statistically significant differences in the importance of shaping resilience for the development of service enterprises in process and product, financial, and market areas between different classes of these enterprises distinguished according to the following criteria: leading business profile, age, scale of operation, and average annual turnover. In other words, representatives of all the surveyed enterprises similarly assessed the importance of shaping resilience for developing service enterprises to "strengthen" innovative enterprises. This may indicate the legitimacy of developing relatively "universal" guidelines/guidelines for shaping organisational resilience and treating it as a "tool" for improving service enterprises. Of course, it should be noted that the research sample was not fully representative, and the conclusions obtained should be applied in principle to the surveyed entities. However, some "generalisations" can be made to the population. It should be remembered that the results of this study are only the "general basis" of managerial decisions. In principle, in every innovative service company, the study's conclusions can be interpreted slightly differently and used to a different extent.

Conclusions

This article focuses on diagnosing the relationship between the development of organisational resilience and the development of innovative service enterprises. Attention was paid primarily to how representatives of innovative service enterprises assess the importance of shaping organisational resilience for the development of their entities (in three areas: process and product, financial, and market). It was also focused on examining whether there are statistically significant differences between different categories of service enterprises (e.g., due to the criterion of age, leading business profile, etc.) in assessing the importance of shaping organisational resilience for the development of enterprises.

Practical recommendations resulting from the research are as follows:

1. Service enterprise managers and owners should identify the principal areas of resilience development and their leading effects, enabling a more precise estimation of a given company's level of development.
2. Shaping organisational resilience can be the "basis" for strengthening innovation activities. Therefore, it is worth consciously managing organisational resilience, not only at the top management level but also at lower levels. A general awareness of the importance of organisational resilience for all employees is critical here. In shaping organisational resilience, a positive synergy effect (employee cooperation) is crucial, thanks to which it will be possible to support innovation processes in many aspects.
3. Finance should be one of the "foundations" for shaping organisational resilience: it can be a kind of "lever" for the organisation's development.
4. When diagnosing the relationship between organisational resilience and the development of innovative service enterprises, it is recommended to use a holistic approach, considering the most significant possible number of factors/conditions that may significantly determine organisational resilience and thus translate into the development of innovative service enterprises.
5. Assessing the importance of organisational resilience should be seen only as one of many "signposts" for managers/business owners. The method of calculation presented in the article has a relatively large "margin of error". Nevertheless, awareness of estimating the importance of organisational resilience is essential. It can change how service companies are managed, e.g., by moving towards a more extensive system for identifying and analysing risk factors.

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Employee attitudes towards organisational diversity: the peculiarities of a manufacturing enterprise

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ABSTRACT
The article explores the impact of attitudes towards diversity on employee proactivity, considering job satisfaction as a mediating variable and the specific characteristics of manufacturing enterprises in contrast to those with other activities. A conceptual model for the relationship between inclusivity, employee proactivity, and job satisfaction was formulated following the literature review. The proposed model underwent empirical testing through confirmatory analysis using structural equation modelling (SEM CFA) on a sample of 1,000 employees. The data were collected in December 2023, focusing on exploring the impact of employee inclusivity on proactivity mediated by job satisfaction. This study compared manufacturing company employees to those working in other types of enterprises. Quantitative research was used to test the model of the relationship between inclusivity and employee proactivity. The results confirmed a positive direct relationship between inclusivity, proactivity, and job satisfaction. Additionally, the study demonstrated the role of job satisfaction as a mediator between inclusivity and proactivity. While no greater impact of inclusivity was affirmed in manufacturing enterprises compared to other types of firms, some differences were observed in this context. The study fills a gap in the links between employee inclusivity and proactivity with the mediation of job satisfaction. Subsequent research would need to further explore the impact of the specific components of the study constructs on employee proactivity and extend to other mediators and moderators of the relationship between the studied variables. For enterprises, the findings indicate the need to implement practices supporting inclusivity and creating work environments that foster satisfied employees. The differences in the magnitude of the impact of inclusivity depending on the type of activity suggest that human resource management practices should be adapted to the organisational context.

KEY WORDS
workplace diversity, employee inclusivity, employee proactivity, job satisfaction, manufacturing employees

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Introduction

Contemporary organisations are challenged by the rapidly changing business environment that requires flexibility, innovation, and adaptation (Chen et al., 2019). In the era of globalisation, organisations have been dealing with increasingly more culturally and demographically diverse teams of employees. Attitudes regarding this diversity can strongly impact organisational performance and, particularly, employee proactivity (Li et al., 2020).

While a body of literature explores attitudes towards diversity and their impact on various facets

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of organisational performance (Kulik, 2014; Roberson, 2019), some gaps in findings remain. They pertain to the distinctive characteristics of manufacturing companies when compared to other types of organisations. Manufacturing companies tend to operate in more complex working environments, where factors such as technology, production processes, and occupational safety dominate. These unique operational aspects influence employee attitudes and behaviours, making it essential to study diversity and inclusivity specifically within this context.

Manufacturing companies often involve work on production lines, characterised by repetitive tasks, stringent quality control, and automated systems (Aldossari & Zin, 2019; Ismail, 1998). These environments require specific skills and present unique challenges, such as physical demands and the need for precise task execution under tight deadlines. Furthermore, workplace safety is paramount in manufacturing settings, with proactive measures crucial to maintaining a safe work environment (Mutegi, Joshua & Kinyua, 2023).

Research insufficiently focuses on manufacturing operations and their correlation with attitudes towards diversity and employee proactivity. Addressing this literature gap can offer valuable insights into the theory and practices of human resource management in manufacturing companies.

This article aims to explore the direct and indirect impact of employee inclusivity on their proactivity through job satisfaction. This examination considers the unique characteristics of manufacturing companies compared to organisations in other business sectors. The analysis of this issue aims to enhance the understanding of the mechanisms underlying employee proactivity concerning their attitudes towards diversity and the organisational context. This study focuses on the peculiarities of manufacturing enterprises and contributes to the broader understanding of diversity management and its impact on employee behaviour in varied organisational contexts.

The article is divided into three parts: (1) a theoretical background encompassing the nature of workplace diversity, inclusivity, proactivity, their relationship with job satisfaction, and the distinctive operational aspects of manufacturing companies; (2) a section detailing the empirical research methodology, including the purpose, assumptions, research sample, and the results of statistical analyses; and (3) a section presenting the study findings in alignment with the existing literature.

1. Literature review

1.1. Determinants of employee attitudes towards diversity

Workplace diversity spans many dimensions, including variations in culture and ethnicity, gender, age, skills, sexual orientation, and professional experience and education (Kostrzewa et al., 2023). Employees may come from diverse cultures, nationalities, or ethnic groups. An integral aspect of diversity is gender equality, incorporating the representation of women and men across all organisational levels. Additionally, diversity extends to equality for LGBTQ+ individuals, encompassing acceptance and support for employees with different sexual orientations. Age diversity pertains to generational differences within a team, involving employees from various age groups like Generations X, Y, Z, or BB (baby boomers). Diversity emerges from diverse employee skills, education, experience, and professional backgrounds (Przytuła, 2019).

Diversity in the workplace contributes to innovation through creativity, increased flexibility, and problem-solving capabilities (Cook, 2016; Gross-Gołacka, 2018; Khairi, 2024). For this reason, employee perceptions of diversity and employee evaluations of diversity management practices should be the subject of systematic research (Mor Barak, 2022).

Diversity-promoting organisations aim to establish an open and inclusive work environment, enhancing employee satisfaction and improving organisational performance (Downey et al., 2015).

Workplace inclusivity aims to cultivate an environment where all employees feel accepted, respected, and valued, irrespective of their differences (Bourke & Titus, 2022). This involves implementing measures to eliminate barriers that may lead to exclusion or injustice. Inclusivity fosters full employee engagement, cooperation, and self-development (Ely & Thomas, 2020). It guarantees that all employees are included, listened to, and can actively contribute to the organisation's activities.

In an organisational context, inclusivity means the removal of physical and psychological barriers that may prevent or hinder the full participation of diverse employee groups (Nishii & Leroy, 2022). Pursuing inclusivity necessitates intentionally designing structures, policies, and practices to cater to diverse needs. The value of inclusivity is to respect

and appreciate differences in a fair and open workplace (Randel et al., 2018).

Inclusivity has the potential to enhance organisational performance. It drives greater innovation and creativity (Veli Korkmaz et al., 2022). It responds to the dynamics of environmental changes, such as the increase in the number of neuroatypical individuals or shifts in demographic structures (the increase in the proportion of seniors). A lack of inclusivity may result in a staffing gap and lead to unnecessary friction and conflicts.

Inclusivity is likely a feature of an organisation committed to values and practices promoting an open and participatory environment for a diverse workforce (Pai, 2021). For an organisation to be inclusive, it is essential for its employees to exhibit an inclusive attitude at an individual level. Organisations and employees create a work environment that is not only diverse but also open, friendly, and supportive for everyone. Individual inclusivity pertains to the readiness and ability of employees to accept, respect, and acknowledge diversity among their colleagues. Those who adopt an inclusive mindset in the workplace attempt to create an atmosphere where everyone feels accepted and valued and has the opportunity to fully contribute, irrespective of their differences (van Knippenberg & van Ginkel, 2021). They demonstrate respect and acceptance towards diversity. They also take measures to support colleagues, eliminate barriers, and engage in practices that foster inclusive participation among all employees (Nishii & Leroy, 2022). Inclusive employees are willing to engage in open dialogue, listen to the views of others and make efforts to understand and incorporate the perspectives of differing individuals. Inclusive individuals are poised for open dialogue, consider diverse opinions, and take proactive steps to understand and incorporate various perspectives.

1.2. Interplay of inclusivity and proactivity

The inclusivity of employees depends on a range of factors, encompassing organisational aspects and individual values, attitudes, and experiences. At the organisational level, inclusivity is shaped by policies and procedures supporting diversity in the workplace, as well as the attitudes of leaders who demonstrate openness, respect, and acceptance of diversity as well as the attitudes of leaders who demonstrate openness, respect, and acceptance of diversity (Randel et al., 2018).

At the individual level, inclusivity is shaped by employees' values and attitudes. Employees who embody openness, respect, and cooperativeness are more likely to create an inclusive environment (Nishii, 2013). Inclusive attitudes are nurtured through life experiences (Maddux & Galinsky, 2009), including exposure to diverse cultures, social groups, or individuals with different sexual orientations. Diverse experiences foster inclusive attitudes and support employee proactivity, contributing to a workplace culture that encourages innovation (Hunt et al., 2015).

Proactive employees take the initiative to drive impactful changes within the organisation. Their proactive efforts, whether initiating or participating in projects, are crucial in cultivating relationships that yield professional and social benefits (Bindl & Parker, 2010). By actively engaging in tasks that involve interaction with others, proactive employees develop and enhance their interpersonal skills. Consequently, this fosters more positive relationships with colleagues, superiors, and clients alike.

The following hypothesis is formulated by drawing insights from an overview of the literature on employee inclusivity and proactivity:

H1: Inclusivity of employees has a positive impact on their proactivity.

1.3. Role of job satisfaction and its impact on proactivity in the context of inclusivity

Proactive employees engage in activities such as volunteering for challenging tasks or undertaking initiatives, which leads to the development of their competences. These efforts positively influence engagement and motivation, contributing to overall job satisfaction and a profound sense of professional fulfilment (Bakker & Albrecht, 2018).

Satisfied employees may be more inclined to solve problems and take proactive measures, including those related to promoting inclusivity. They are also more prone to sharing ideas, suggestions, and opinions (Harter, Schmidt & Hayes, 2002). This state of play, in turn, fosters the exchange of diverse perspectives stemming from an inclusive mindset.

Job satisfaction facilitates a positive workplace atmosphere, a notion further supported by team diversity within teams (Novianti et al., 2022). Satisfied employees exhibit a greater willingness to collaborate. Also, they are more open to building positive relationships with their colleagues. Strong employee

relationships can contribute to job satisfaction by influencing mutual respect and understanding (Juchnowicz, 2014).

The following hypotheses are formulated drawing on the literature review on the relationship between proactivity, job satisfaction and employee inclusivity:

H2: Employee inclusivity has a positive impact on job satisfaction.

H2a: Employee inclusivity fosters job satisfaction and positively impacts employee proactivity.

1.4. Unique characteristics of manufacturing companies and the influence of job satisfaction on employee proactivity in the context of inclusivity

Manufacturing companies differ from other types of companies by the specifics of their operations. Employee attitudes are shaped by the unique aspects of manufacturing operations (Bulut et al., 2019), encompassing tasks such as working on the production line, job security or production flexibility.

Work on the production line is more focused on specific activities. It relies on task division and specialisation. Each employee performs specific, often repetitive activities. Work is organised in cycles, following a defined production pace. The repetitive nature of tasks is a distinctive feature of the production line work, contributing to its perception as monotonous. Additionally, some tasks may be physically demanding, resulting in employee fatigue.

Work on the production line often follows strict quality standards (Ismail, 1998). Employees undergo frequent observation and are pressured to meet deadlines. Each stage of the production process must be executed precisely and within a specified timeframe. Even minor deviations from the norm can significantly affect the quality and efficiency of production.

Modern production lines often rely on automated systems, where numerous activities are performed by machines and equipment, with workers responsible for overseeing and maintaining these processes (Aldossari & Zin, 2019). Simultaneously, teamwork and coordination are often essential in production line roles. Employee satisfaction may depend on effective collaboration skills, and workers' proactivity is manifested in initiatives to improve communication and team integration.

Workplace safety stands as a major facet in the operations of manufacturing companies (Mutegi et al., 2023; Sarwar et al., 2019). The satisfaction of employees can stem from the organisation's commitment to ensuring a secure working environment, and the proactive engagement of workers may be demonstrated through initiatives aimed at enhancing safety procedures.

The following hypotheses were formulated based on the literature review on the nuances of manufacturing companies:

H3: Employee inclusivity has a stronger effect on job satisfaction in manufacturing enterprises than in other types of businesses.

H3a: By boosting job satisfaction, employee inclusivity influences proactivity with greater force in manufacturing enterprises than in other types of businesses.

2. Research methods

2.1. Research sample characteristics

In December 2023, a quantitative survey was conducted to examine the model of the relationship between inclusivity, proactivity, and job satisfaction. The survey targeted a sample of economically active Poles (N=1000). It employed the CAWI method, utilising a nationwide accredited survey panel. The representativeness of the sample was ensured through random sampling. Notably, nearly 20 % of the respondents were production workers (198 people), while the remaining participants (802 people) were employed in non-manufacturing organisations.

The acquired sample was balanced in terms of age and organisation size. Production workers predominantly had secondary education (52 %), while in the overall sample and other non-manufacturing enterprises, those with higher education prevailed (56 % and 61 %, respectively). Over 80 % of respondents were employed on full-time employment contracts, and more than 70 % held non-managerial positions. The majority were employed in the private sector (92 % of production workers). Within the production sector, the sample was gender balanced (53 % women and 47 % men). In the entire sample and across other industry sectors, the majority comprised women (68 % and 71 %, respectively). Table 1 presents the comprehensive breakdown of the research sample and its segmentation into production and other industry sectors.

Tab. 1. Research sample structure

Criterion	Specification	Entire Sample	Manufacturing	Other Forms of Business Activity
Gender	Female	68 %	53 %	71 %
	Male	32 %	47 %	29 %
Generation	Z	30 %	25 %	31 %
	Y	30 %	30 %	30 %
	X	30 %	35 %	29 %
	BB	10 %	10 %	10 %
Education	Primary	1 %	2 %	1 %
	Vocational	6 %	10 %	5 %
	Secondary	37 %	52 %	33 %
	Higher	56 %	37 %	61 %
Job level	Non-managerial	74 %	74 %	73 %
	Managerial	20 %	23 %	20 %
	Owner	6 %	3 %	7 %
Working Hours	Full time	87 %	95 %	85 %
	Part-time	13 %	5 %	15 %
Employment Type	Employment contract	83 %	93 %	80 %
	Civil law contract	11 %	5 %	12 %
	Proprietorship	7 %	2 %	8 %
Company Size	micro (up to 9 employees)	15 %	5 %	18 %
	small (from 10 to 49 employees)	23 %	22 %	24 %
	medium (from 50 to 249 employees)	25 %	28 %	25 %
	large (from 250 to 500 employees)	14 %	19 %	13 %
	very large (above 500 employees)	23 %	27 %	22 %
Sector	Public	22 %	8 %	26 %
	Private	75 %	92 %	70 %
	foundations, associations, and others	3 %	-	4 %

2.2. Variables

The survey used a questionnaire to measure employee inclusivity (3 items), proactivity (3 items), and job satisfaction (3 items). Respondents rated the items on the 5-point Likert scale, where 1 means "strongly disagree" and 5 means "strongly agree".

The analyses were conducted using SPSS AMOS software (version 29).

The dependent variable in the model was "Proactivity". The explanatory variables were "Inclusivity" and "Job satisfaction".

"Proactivity" was measured using three statements that explored declarations of creating ideas for improvements, affecting how work is performed, and undertaking new tasks to improve work.

"Inclusivity" was measured using three survey items that described having no difficulty in cooperating with different people, supporting others in achieving their professional goals, and adapting communication to the diversity of co-workers.

"Job satisfaction" was assessed using three items: job enjoyment, pride and a sense of purpose in one's work.

All the variables were constructed reflectively.

2.3. Analytical strategy

The research aimed to assess the quality of the conceptual model assuming the relationship between inclusivity, proactivity, and job satisfaction while considering the impact of specific manufacturing work. In the model, latent variables were employed, i.e., variables that cannot be observed directly but can be detected through other observable variables. The Confirmatory Factor Analysis (CFA) was used to

verify the structure of the variables, and the path analysis was applied to assess the relationships between the identified latent variables. A three-step approach was employed. First, Confirmatory Factor Analysis (CFA) was conducted to assess the measurement model fit indices ($\chi 2$ test, RMSEA, CFI, TLI, SRMR) and path coefficients. Then, the measurement scales used in the research were assessed for their reliability as well as convergent and discriminant validity. Finally, the hypotheses were verified using three structural models.

3. Research results

3.1. Descriptive statistics

The descriptive statistics and the correlations between the variables are presented in Table 2. The respondents rated "Inclusivity" at the highest level (mean = 3.96) and "Proactivity" at the lowest level (mean = 3.57). The obtained mean values for manufacturing enterprises were slightly lower than those for non-manufacturing organisations. The correlations between the variables were statistically significant, ranging from 0.472 (for "Job satisfaction" and "Inclusivity") to 0.528 (for "Job satisfaction" and "Proactivity") for the entire sample. In the case of manufacturing enterprises, the correlation of "Proactivity" with "Inclusivity" and "Job satisfaction" was slightly higher than that for organisations with other activities, while the correlation of "Inclusivity" with "Job satisfaction" was slightly lower.

3.2. Measurement model

The CFA was used to validate the measurement model. The values of the fit indices GFI = 0.981 and AGFI = 0.964, NFI = 0.976 and CFI=0.982 were above the threshold value of 0.9. SRMR (0.03) and RMSEA (0.051) were at the right level and did not exceed the value of 0.08, which is considered the threshold for acceptable models, and the confidence interval for RMSEA did not contain a value of 0.1 that would disqualify the model (Table 3).

The standardised estimates for path coefficients between the statements and each construct were significant and exceeded the 0.5 coefficient value (Table 4).

The construct validity was assessed using composite reliability (CR), average variance extracted (AVE), and discriminant validity. The reliability was tested with Cronbach's α coefficient and CR index. All Cronbach's α values approached or exceeded 0.70, with CR values ranging from 0.678 to 0.879, i.e. near and above the threshold value of 0.7, thus confirming internal consistency. The convergent validity was assessed using the AVE coefficient, which ranged from 0.414 to 0.707, exceeding for two of the three constructs the standard threshold of 0.5 for conver-

Tab. 2. Descriptive statistics and correlations

Entire Sample					
Variable	**Mean**	**Standard deviation**	**1**	**2**	**3**
1. Proactivity	3.569	0.848	1		
2. Inclusivity	3.959	0.844	0.507**	1	
3. Job satisfaction	3.646	1.008	0.528**	0.472**	1
Manufacturing					
Variable	**Mean**	**Standard deviation**	**1**	**2**	**3**
1. Proactivity	3.539	0.861	1		
2. Inclusivity	3.916	0.868	0.539**	1	
3. Job satisfaction	3.517	1.007	0.537**	0.453**	1
Other types of business activity					
Variable	**Mean**	**Standard deviation**	**1**	**2**	**3**
1. Proactivity	3.577	0.845	1		
2. Inclusivity	3.970	0.838	0.499**	1	
3. Job satisfaction	3.678	1.007	0.525**	0.476**	1

**. Significant correlation at the 0.01 level (two-tailed)

Tab. 3. Fitting the measurement model to the data

Statistics	Value	Threshold value
Chi-square and df	86.530, df=24	-
GFI	0.981	> 0.9
AGFI	0.964	> 0.9
NFI	0.976	> 0.9
CFI	0.982	> 0.9
SRMR	0.030	< 0.08
RMSEA	0.051	< 0.08

Tab. 4. Model variables

Variable	Item	Path coefficient
Proactivity	I am creative and have lots of ideas for improving my work.	0.682
	I have a say in how I do my work.	0.552
	I often pick up new tasks at work, not as part of duty, but just to make something better or more efficient.	0.688
Inclusivity	I don't find it difficult to work with people who differ from me in terms of background, age, gender or some other way.	0.667
	I actively support all my colleagues in reaching their professional goals, no matter their age, gender, background.	0.770
	I adapt the way I communicate depending on the diversity of colleagues in my team in terms of their age, gender, or background.	0.715
Job Satisfaction	I enjoy my job; I tend to go to work with pleasure.	0.806
	I believe that my work serves a purpose.	0.858
	I take pride in my work.	0.858

Tab. 5. Psychometric property assessment of scales

Variable	CR	AVE	α	Correlations /Square root of AVE *		
				1	2	3
1. Proactivity	0.678	0.414	0.672	0.644		
2. Inclusivity	0.761	0.516	0.761	0.720	0.719	
3. Job satisfaction	0.879	0.707	0.878	0.662	0.576	0.841

CR — Composite Reliability, AVE — Average Variance Extracted, α — Cronbach's α

* The AVE square root appears on the diagonal.

gent validity. The discriminant validity was verified using the Fornell-Larcker criterion (Fornell & Larcker, 1981). According to this criterion, the AVE square root should be greater than the correlation between the constructs. The condition was met, excluding two correlations (Table 5).

3.3. Estimation of structural models

The path coefficients were estimated to examine the relationships between "Inclusivity", "Proactivity", and "Job satisfaction" across the sample (Table 6).

The variables in the model under study explained more than 60.9 % (R2=0.609) of the variance in "Proactivity" and 33.2 % (R2 = 0.332) of the variance in "Job satisfaction".

The findings supported the hypotheses of a positive direct effect of "Inclusivity" on "Proactivity" (H1) (β= 0.507, p<0.001) and on "Job satisfaction" (H2) (β= 0.576, p<0.001). Furthermore, they also supported the hypothesis that "Job Satisfaction" enhanced the impact of "Inclusivity" on "Proactivity" (H2b) (indirect effect β= 0.213, p<0.001).

Tab. 6. Path coefficients for the studied variable relationships

Structural paths	Path coefficients
Inclusivity -> Proactivity (direct effect)	0.507*
Inclusivity -> Job satisfaction (direct effect)	0.576*
Inclusivity -> Job satisfaction -> Proactivity (indirect effect/total effect)	0.213*/ 0.720*

*p<0,001;

Tab. 7. Path coefficients and fitting of structural models for manufacturing and other activities

Structural path	Manufacturing	Other activities
Inclusivity -> Proactivity (direct effect)	0.493*	0.524*
Inclusivity -> Job satisfaction (direct effect)	0.549*	0.586*
Inclusivity -> Job satisfaction -> Proactivity (indirect effect/total effect)	0.215*/ 0.708*	0.204*/ 0.728*
Chi-square and df	34.598. df=24	78.391. df=24
GFI	0.964	0.978
AGFI	0.933	0.959
NFI	0.957	0.972
CFI	0.986	0.981
SRMR	0.034	0.034
RMSEA	0.047	0.053

*p<0.001

3.4. Manufacturing versus non-manufacturing enterprises

Two separate SEM models were estimated to examine the impact of specific manufacturing activities on the relationships between "Inclusivity", "Proactivity", and "Job satisfaction" (Table 7).

The values in Table 7 indicate a good fit of both models to the data.

The variables in the model under study explained more than 60 % (R2=0.609) for manufacturing and 61 % (R2=0.610) for other activities of the variance in "Proactivity" and more than 30 % (R2=0.301) for manufacturing and 34 % (R2=0.344) for other activities of the variance in "Job satisfaction".

The findings did not support the two hypotheses about the greater impact of "Inclusivity" on the "Proactivity" of employees in manufacturing enterprises as compared to the other activities (H3 and H3a). In manufacturing, "Inclusivity" had a slightly less powerful effect on "Proactivity" directly (for manufacturing β= 0.493, p<0.001, for others β= 0.524, p<0.001) and indirectly through "Job Satisfaction" (total effect for manufacturing β= 0.708, p<0.001, for others β= 0.729, p<0.001). Meanwhile, the indirect effect of the impact of "Job Satisfaction" on the relationship between "Inclusivity" and "Proactivity" was slightly higher in manufacturing enterprises (for manufacturing β= 0.215, p<0.001, for others β= 0.204, p<0.001).

4. Discussion of the results

The study findings extend the knowledge of the interplay between inclusivity, proactivity and job satisfaction.

The results support several studies suggesting a positive direct relationship between inclusivity and positive outcomes in terms of employee job satisfaction and proactivity (Cox, 1993; Shore et al., 2011). Workplace inclusivity fosters a sense of belonging and acceptance, as well as the opportunity to voice thoughts and ideas, which in turn boosts the employees' efforts to take initiative when dealing with problems (Cox, 1993).

This research adds further evidence that job satisfaction is a significant mediator between employee inclusivity and proactivity. As such, it aligns with previously published research indicating that job sat-

isfaction may be one of the mechanisms through which an inclusive work environment contributes to improved work performance (Morgeson & Humphrey, 2006; Shore et al., 2018).

The lack of support for the hypothesis that the effect of inclusivity on proactivity is more powerful in manufacturing firms compared to other types of enterprises aligns with some previous research suggesting that the effect of inclusivity on work performance is universal and independent from the industry sector (Shore et al., 2011).

However, this research did reveal some differences in the magnitude of the impact of inclusivity on proactivity depending on the type of organisation. This suggests that the organisational context is likely to influence the relationship between employee inclusivity and proactivity, which may have implications for personnel management practice across a range of sectors (Shore et al., 2011).

The study's comparative analysis between manufacturing and non-manufacturing organisations revealed sector-specific nuances. In manufacturing enterprises, inclusivity had a slightly less powerful direct effect on proactivity compared to non-manufacturing organisations. This suggests that while inclusivity promotes proactive behaviours in both sectors, the structured and often repetitive nature of manufacturing work might moderate this relationship. The direct effect of inclusivity on job satisfaction in manufacturing enterprises was also slightly lower than in non-manufacturing sectors. The stringent operational demands and focus on safety and precision in manufacturing might influence how inclusivity translates into job satisfaction. Additionally, the mediation effect of job satisfaction on the relationship between inclusivity and proactivity was more significant in manufacturing enterprises compared to non-manufacturing organisations. This highlights the critical role of job satisfaction in translating inclusive practices into proactive behaviours in manufacturing settings, where job roles and expectations are more rigidly defined.

The findings have implications for both the theory and practice of diversity management. To leverage the benefits of inclusivity, manufacturing firms should focus on enhancing job satisfaction as a mediator. This could involve implementing inclusive practices that address the unique operational challenges of the sector, such as improving workplace safety and ergonomics and fostering a supportive work environment that values each employee's contributions. In non-manufacturing settings, inclusive practices can have a more direct impact on proactivity. Strategies could include promoting flexible work arrangements, encouraging diverse team collaborations, and providing opportunities for creative and proactive problem-solving.

The positive relationship between inclusivity, job satisfaction, and proactivity is consistent across both sectors, emphasising the universal value of inclusive practices. Organisations, regardless of their sector, should prioritise inclusivity to foster a more proactive and satisfied workforce.

Conclusions

The conducted research has broadened the view on the relationship between inclusivity, proactivity, and job satisfaction. Its findings confirmed a positive direct effect of inclusivity on proactivity and job satisfaction and revealed the role of job satisfaction as a mediator between inclusivity and proactivity. This proves the importance of employee attitudes towards diversity in the workplace (Mor Barak, 2022). The research did not confirm the greater magnitude of the impact of inclusivity in manufacturing enterprises compared to those with other activities. Nevertheless, some differences have been observed in this context, which supports the view that "diversity has many faces", and therefore, no universal and single approach exists to analysing this issue (Przytuła, 2019). The research indicates that inclusivity affects employee proactivity in different organisational contexts, which holds major implications for both the theory and practice of human resource management. These findings may be of value to those organisations that seek to create more inclusive workplaces and to those scholars who are interested in the mechanisms through which inclusivity influences the actions of employees.

Although the research has made an important contribution to the understanding of the relationships between inclusivity, proactivity, and job satisfaction, some constraints need to be recognised when it comes to interpreting the results.

The research was based on the data collected at a single time point, which prevents conclusions about the directionality of the relationship between the studied variables. Any future research could focus on analysing data collected at different time points to understand the long-term effects of inclusivity on proactivity and job satisfaction.

In fact, it is possible that some other variables not included in the model may also act as mediating vari-

ables in the relationships between inclusivity, proactivity, and job satisfaction. The focus of future research could be on identifying the mechanisms through which inclusivity affects proactivity as well as on the moderating and mediating factors that influence these relationships.

Despite care in the design of measurements, there is a risk of errors associated with the type of scales used, which may affect the accuracy of the results. Future research should consider the design of increasingly accurate scales.

It is possible that other contextual factors, beyond the analysed types of activities, might influence the examined variable relationships. Future research could integrate various organisational contexts to understand how inclusivity affects proactivity and job satisfaction across different sectors and types of organisations.

In the future, some follow-up research is advisable to gain a better understanding of the causality of the relationship between inclusivity, proactivity and job satisfaction, as well as research that considers such dimensions of inclusivity as gender equality, cultural diversity or integration of disabled people to clarify how they affect proactivity and job satisfaction.

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Assessing the resilience of the Baltic air transport sector in the context of economic crises

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ABSTRACT

The significance of this study lies in assessing the resilience of the air transport sector to economic crises, which is crucial in today's context where sustainable environmental development has become a new reality, and the development of aviation services is insufficient for achieving stable and resilient economic growth in the sector. The air transport sector significantly contributes to regional economic growth and the development of various other business sectors. This article evaluates the resilience of the air transport sector in the Baltic countries in the context of economic crises. The novelty of the research stems from the air transport sector undergoing entirely new and unexplored processes, significantly influenced by the COVID-19 pandemic and previous crises, such as the September 11 attacks and the Great Financial Crisis. There is a lack of a comprehensive evaluation model to assess the resilience of the air transport sector under economic instability. The article aims to assess the resilience of the air transport sector in the Baltic countries in the context of economic crises. The article describes external factors influencing the economic growth of the air transport sector. It examines the perspectives of different authors and institutions on the development of the air transport sector. The study analyses national and international documents, development plans, and investments related to enhancing the resilience of the air transport sector to economic crises. To assess the resilience of the air transport sector in the Baltic countries in the context of economic crises, an empirical study was conducted using the following methods: Pearson correlation coefficient method to evaluate the relationship between Revenue Passenger Kilometers (RPK) and Available Seat Kilometers (ASK) indicators of the sole national airline in the Baltic States, "Air Baltic", which belongs to Latvia, crucial for ensuring comprehensive stability; a multi-criteria evaluation using Simple Additive Weighting (SAW) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods to assess the current state and recovery level of the Baltic air transport sector after the COVID-19 pandemic; and an exponential smoothing method to forecast the growth of the Baltic air transport sector from 2024 to 2027, providing a realistic scenario.

KEY WORDS

air transport sector, resilience, Baltic airports, flights, economy, sustainability COVID-19, economic crisis

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Introduction

The air transportation system is paramount to our societies, reflecting the technological advancements driven by societal needs and global interconnectedness (Wandelt et al., 2025). Assessment of the resilience of the air transport sector is crucial to ensure the sector can continue sustainable economic growth even in the context of economic crises. The sector's ability to efficiently respond to changing consumer needs is essential, given its economic sensitivity and potential to adapt quickly to dynamic circumstances. In the current operating environment,

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a broader range of services is required to attract diverse consumer groups and reduce the sector's vulnerability.

The air transport sector in the Baltic countries is implementing significant development projects focused not only on expanding flight networks and infrastructure but also on comprehensive sustainability. Strategies that enable the sector to operate efficiently even under economic uncertainty have become a primary source of resilience and flexibility. The Baltic air transport sector has a crucial impact on regional economic growth, social and economic integration, tourism, and international cooperation. It is important to ensure that during economic crises, the sector remains as resilient as possible, continuing its operations or, when challenged, quickly recovering and adapting to changing market conditions.

Expanding the air transport sector to include non-aviation services increases its resilience and strengthens national economies, providing a solid foundation to overcome future challenges.

The Baltic air transport sector lacks comprehensive tools for accurately assessing its resilience to economic crises. The COVID-19 pandemic has exposed the sector's vulnerabilities and highlighted the need for new strategies to adapt to changing conditions. Existing studies fail to provide an integrated framework that combines qualitative and quantitative indicators. Therefore, developing a methodology that enables a holistic assessment of the sector's resilience and supports informed decision-making is essential.

Despite ongoing global and political uncertainties, political conflicts or economic recessions, the air transport industry is steadily growing. The long-term growth rate of air passenger transport since 1970 is around 5.5 % (Çelik et al., 2025). Implementing certain key policies has significantly enhanced the sector's resilience during major economic crises; however, the network remains vulnerable to disruptions for some time, particularly in its most critical hubs (Deng et al., 2025).

To objectively assess the efficiency of air transport sector development in the Baltic countries, the following structural elements were chosen: airports, air carriers, and air traffic.

The first section, the Literature Review, examines the theoretical foundations and definitions of resilience, focusing on its relevance to the air transport sector. It reviews key scholarly works, identifies gaps in existing research, and discusses the interrelationship between resilience, sustainability, and economic adaptability, particularly in the context of crises.

The second section, Research Methods, details the methodology used to assess the resilience of the Baltic air transport sector. It includes using quantitative methods such as the Pearson correlation coefficient, multi-criteria evaluation (SAW and TOPSIS), and exponential smoothing. These methods evaluate the sector's performance and predict future growth. Key performance indicators, including Revenue Passenger Kilometers (RPK), Available Seat Kilometers (ASK), Employment (EMP), and Instrument Flight Rules (IFR), are introduced and explained.

The third section, Research Results, presents the findings from the empirical study. It highlights the recovery trajectory of the sector following the COVID-19 pandemic, evaluates resilience using the SAW and TOPSIS methods, and forecasts growth using the exponential smoothing method. This section provides insights into the sector's recovery and identifies the key drivers of its resilience.

The fourth section, Discussion, interprets the research results within the context of broader economic and operational challenges faced by the air transport sector. It explores the implications of the findings, emphasising the critical role of sustainability, non-aviation services, and adaptability in enhancing resilience. Additionally, it analyses key lessons learned from the COVID-19 crisis and other disruptions, providing a comprehensive understanding of the sector's capacity to withstand and recover from economic shocks.

Finally, the fifth section, Conclusions, summarises the study's main findings and their implications for the Baltic air transport sector. It offers practical recommendations for policymakers and industry stakeholders, highlighting strategies to enhance sector resilience and sustainability. The conclusions also provide directions for future research, emphasising the need for further exploration of resilience-building approaches to ensure long-term stability and growth in the sector. This structure ensures a logical progression of ideas, guiding readers seamlessly from theoretical concepts to practical applications and policy insights.

1. Literature review

Resilience is defined differently in scientific literature and is most often associated with economic recovery following shocks (Martin et al., 2015). Economic resilience refers to the self-restoration and adaptability of an economy following external shocks.

Greater economic resilience can help an economy quickly return to previous growth trajectories or reallocate resources to new growth directions (Martin et al., 2015; Okuneviciute Neverauskiene et al., 2021; Okuneviciute Neverauskiene et al., 2025).

Researchers are increasingly expanding the concept of resilience in their studies, recognising that resilience should encompass the ability to restore a system to its original state and promote system recovery (Zhong et al., 2024). An economy must be able to absorb shocks and adapt to them quickly and have the capacity to change its structure and transition to a new growth path following external shocks. Thus, economic resilience is defined by its adaptability and transformation capabilities (Pan et al., 2023).

Other perspectives in the literature argue that it is not enough to have resources to reallocate; clear analytical alternatives are also needed to guide resource distribution, given that even entities within the same sector operate under different conditions. Effective economic resilience to crises requires tangible resource allocation models to analyse trade-offs between resilience dimensions (Dormady et al., 2019).

As research on resilience and its understanding progresses, particularly regarding future perspectives, resilience becomes inseparable from sustainability. Modern challenges include environmental issues such as species extinction, climate change, ecosystem degradation, and resource depletion. The juxtaposition of sustainability and resilience concepts emerged to address these critical issues and prepare for the future. These efforts depend on the effective management of natural resource markets, which are crucial for economic growth, ecological sustainability, and social well-being.

Exploring the complex interaction between resilience, sustainability, and efficiency aims to understand how this dynamic can drive recovery initiatives and create a more resilient future. Given the current instability and insecurity, there is a heightened need to enhance sustainability and resilience. Systems' ability to absorb shocks, adapt to changes, and recover quickly has become key in facing significant disruptions such as climate-related disasters and global pandemics. In contrast, sustainability advocates for a world where current and future generations can live harmoniously, meeting their material and environmental needs without sacrificing social or environmental justice or economic progress. The United Nations' Sustainable Development Goals (SDGs) emphasise the interdependence of these elements (Yu & Ye, 2024).

Understanding the complexity of resilience is crucial; the pursuit of economic resilience should not hinder the goal of becoming an environmentally neutral sector (Wang et al., 2024). Currently, as environmental sustainability and economic stability are pressing issues, much attention is given to the relationship between financial practices, ecological well-being, and economic resilience (Okuneviciute Neverauskiene et al., 2021; Cao & Tao, 2023). The relationship between sustainability and resilience is increasingly interlinked.

The air transport sector is transitioning to a new phase where the development of non-aviation services is becoming as important as aviation services. The sector has evolved from a "people-moving machine" to a "people business". Non-aviation revenue sources are diverse: retail, food and beverages, parking, advertising, car rentals, customer service, and real estate (International Air Transport Association, 2023).

A review of the scientific literature identified several factors that significantly influenced the resilience of the air transport sector during the COVID-19 pandemic: travel restrictions and perceived safety risks of air travel (Su et al., 2023). As the recovery process continues, cooperation among various air transport sector companies is likely to expand (Gabriel Bae et al., 2021). In a recent study, researchers identify historical improvements in social conditions as an important factor in explaining the decline in air passenger numbers during COVID-19. The need for long-haul travel is being replaced by virtual meetings, a factor that air carriers should consider to be prepared for future risks (Bergantino et al., 2024).

Resilience assessments in the sector have only recently begun and have increased significantly during and after the COVID-19 pandemic. Maintaining resilience during difficult times is crucial, so interest in the sector's resilience is rapidly growing (Cook et al., 2023). Increasing research on the resilience and recovery of the air transport sector shows that lessons learned from the COVID-19 crisis have significantly strengthened the sector both technologically and strategically.

Gradual changes and more extreme climate-related events will impact the air transport sector's operations, infrastructure, and economy. Given aviation's importance to global connectivity and mobility, it is essential for the sector to understand and adapt to these risks (Burbidge et al., 2023). With a resilient management approach, companies must be prepared to respond to changes and anticipate them, overcom-

ing challenges and maximising opportunities. This readiness allows companies to remain resilient and competitive, gaining a competitive advantage by being prepared to face challenges and adapt to changes (Bakreen et al., 2022).

In the scientific literature, many resilience-like concepts are compared, including robustness, redundancy, ingenuity, rapidity, diversity, efficiency, autonomous components, strength, collaboration, adaptability, mobility, accessibility, safety, recovery, absorption, reliability, vulnerability, risk, and sustainability. Several recent reviews also indicate that resilience is a multidimensional concept with no unified definition (Wang et al., 2023). To fully utilise the concept of resilience, it is essential to consider the critical factors of resilience, robustness, recoverability, and adaptability (Janeckova, 2023). Recent literature calls on researchers to develop indicators to measure the current level of resilience so that users can anticipate problems from early signals of potential vulnerabilities (Feo-Valero et al., 2024). Reviewing the scientific literature and evaluating different yet interrelated perspectives made it clear that the concept of resilience is evolving in response to the changes brought by globalisation (Table 1).

The study will further examine the resilience of the air transport sector in the context of economic crises, where integrated sustainability is the normal operating environment.

The development of non-aviation services/products is becoming increasingly important for the Baltic air transport sector, particularly in achieving resilience under economic instability. The COVID-19 pandemic demonstrated the high vulnerability of aviation, as any safety-related disruptions result in grounded planes, causing substantial losses.

Different definitions of resilience can lead to varying dimensions for its quantitative assessment based on one or multiple criteria. Several researchers have explained related concepts from different perspectives to better compare the differences and similarities between resilience dimensions. Based on performance indicators used for measurements, scientists have identified three related concepts in their studies: reliability, vulnerability, and resilience. They summarised four types of performance indicators: travel time, connectivity, accessibility, and capacity. Other researchers compared several related concepts (e.g., risk, reliability, robustness, vulnerability, sustainability, and safety) facing disruption threats, linguistic characteristics, and system responses. While they provided valuable insights into resilience definitions and quantitative metrics, there are two limitations. First, resilience definitions and connotations overlap with other concepts. Second, resilience definitions are general and not specific to the air transport sector (Wang et al., 2023).

Resilience is most commonly measured using standard economic indicators such as GDP growth and employment. However, specific indicators such as business formation and patenting are also used (Martin et al., 2015; Papaioannou, 2023; Okuneviciute Neverauskiene et al., 2024). Generally, resilience assessment studies employ various methods, such as historical data analysis, to evaluate the air transport sector's resilience during crises and simulate hypothetical scenarios to provide recommendations to air transport companies facing such crises. Some studies use only quantitative or qualitative methods, while others combine them.

The global air transport demand recovery is assessed by RPK (International Air Transport Association, 2022). RPK is an airline industry metric showing the distance paying passenger travel. It is calculated as the number of revenue-paying passengers multiplied by the total distance travelled. As this

Tab. 1. Definitions of resilience in scientific literature

Author	Year	Definition
Martin R; Sunley P; Tyler P;	2015	Self-restoration and adaptability of an economy following external shocks.
Zhong F; Chen R; Luo X; Song X; Ullah A;	2024	Ability to restore a system to its original state and promote system recovery.
Pan S; Hu T; You J; Chang S;	2023	Economic resilience defined by adaptability and transformation capabilities.
Dormady N; Roa-Henriquez A; Rose A;	2019	Choice of analytical alternatives. Tangible resource allocation models are needed to analyse trade-offs between resilience dimensions.
Wang J; Liao F; Wu J; Sun H; Wang W; Gao Z;	2024	Resilience is a multidimensional concept with no unified definition.

Source: author's elaboration on the basis of (Martin et al., 2015; Zhong et al., 2024; Pan et al., 2023; Dormady et al., 2019; Wang et al., 2024).

metric indicates actual air transport demand, it is often referred to as airline traffic. RPK forms the basis of many transport indicators. ASK is another similarly important metric for assessing the air transport sector's recovery. Airlines must align their supply (ASK) with market demand (RPK). A shortage of seats often leads to higher airfares, while excess capacity can increase fixed costs. Thus, capacity growth is positive only if it matches increased air transport demand (Airline Geeks, 2016). Another significant metric for assessing the air transport sector's recovery is Air Transport Movement (IFR), which is the sum of take-offs and landings performed under instrument flight rules (Law Insider, 2024.).

European civil-military organisation dedicated to supporting European aviation (Eurocontrol) study on European traffic development and recovery after previous crises showed that it took the air transport sector 1.5 years to recover and return to previous levels after the September 11, 2001, attacks in the US (Statfor, 2020). The terrorist attacks on the World Trade Center and the Pentagon were not only attacks on the United States but also on the global air transport system (International Air Transport Association, 2021). In response to this crisis and aiming to adapt and remain resilient, the air transport sector implemented security measures, leading to today's high security standards in airports, aircraft etc. From an economic perspective, September 11 brought a wave of financial devastation to the air transport sector (International Air Transport Association, 2021).

Another crisis studied by Eurocontrol was the Great Financial Crisis, after which it took the air transport sector eight years to return to its pre-crisis state (Statfor, 2020). The global downturn affected the finances of air transport companies in both passenger and cargo transport. While reduced demand was expected to be part of a cyclical downturn, the crisis started sooner and hit harder than most experts anticipated (Franke & John, 2011).

The crisis further examined by Eurocontrol is the COVID-19 pandemic. Many researchers are currently studying the pandemic's impact on the air transport sector's economy, and the final results and lessons learned are still unclear. However, according to Eurocontrol research, COVID-19 caused the most significant downturn compared to the aforementioned economic crises. Rational decision-making suggests that based on logic and data, managers will choose an alternative with the highest subjective expected value. However, the rapid onset of COVID-19 and the relentless news cycle brought tension and negative sentiments into the community, triggering emotional reactions. Both information overload and emotions compromise the rationality of managers and consumers, making it especially difficult to make appropriate decisions (Tisdall & Zhang, 2020).

Based on the International Air Transport Association 2021 data, the following table clearly shows the comparison of major economic crises in the air transport sector (Table 2).

Each major economic crisis has different impacts on the air transport sector, not only due to the varying nature of the crises themselves but also because of the different contexts in which they occur. The era and its characteristics during which a crisis manifests play a crucial role; thus, the effects can significantly vary in the present and future.

The air transport sector in the Baltic countries — Lithuania, Latvia, and Estonia — exhibits several key features that influence its operations and development. These countries, located in a geographically strategic position between East and West, leverage their location to become a significant European air transport hub. The Baltic countries are well-positioned to act as a bridge between Eastern Europe, Scandinavia, and other Western European countries, facilitating the development of both passenger and cargo air transport services.

The Baltic States have a single national carrier, A/S Air Baltic Corporation, which, according to the Lat-

Tab. 2. Impact of the September 11 attacks, the 2008 Great Economic Crisis, and the COVID-19 pandemic on the air transport sector

	September 11 attacks (2000–2001)	2008 Great Economic Crisis (2008–2009)	COVID-19 pandemic (2019–2020)
RPKs	- 2.9 proc.	-1.2 proc.	- 65.9 proc.
Yield	- 6.4 proc.	- 16.5 proc.	- 55.6 proc.
Flights	1.1 proc.	-1.3 proc.	- 39.9 proc
Profit fluctuation	- USD 12.2 billion	- USD 40.8 billion	- USD152.8 billion

Source: author's elaboration on the basis of (International Air Transport Association, 2021).

vian Ministry of Transport, substantially influences the region's air transport sector. Therefore, it is essential to assess this key player's RPK and ASK (Fig. 1).

The graph and accompanying data clearly illustrate the performance of A/S Air Baltic Corporation during the period from 2019 to 2023, particularly in terms of ASK and RPK indicators. The example of A/S Air Baltic Corporation from 2019 to 2023 demonstrates the dramatic impact of the COVID-19 pandemic on the air transport industry, followed by a resilient recovery phase. The initial sharp decline in ASK and RPK in 2020 highlighted the immediate impact of the pandemic. In the subsequent years, a steady recovery was observed, with strategic increases in capacity ASK and a stronger rebound in demand (RPK).

IFR is another indicator that vividly reflects the situation of the Baltic air transport sector and can be used to assess the sector's resilience and recovery post-crisis (Fig. 2).

The chart reflects the impact of the pandemic on air transport in the Baltic region, followed by a recovery period from 2021 to 2023. The nearly parallel movement of departures and arrivals throughout the years also indicates that the volume of incoming and outgoing air traffic in the Baltic countries remains consistent over time.

The Baltic air transport sector is intrinsically linked with continuous digitisation and the integration of advanced technologies, which are essential for enhancing operational efficiency and providing high-

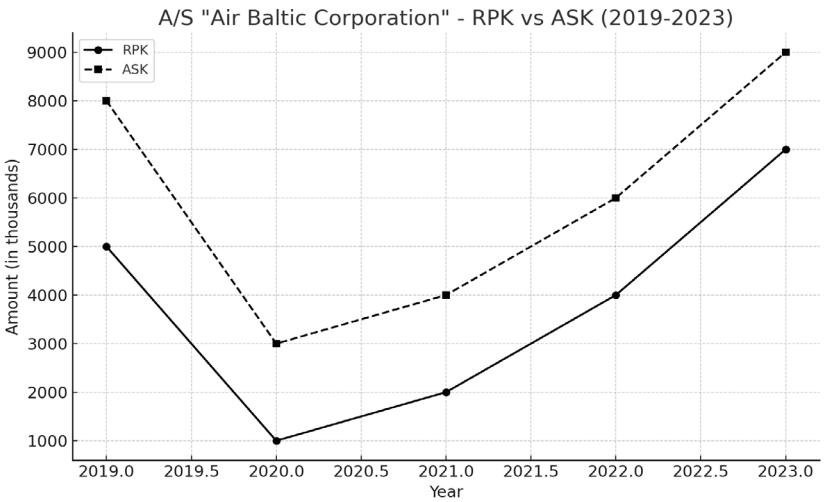
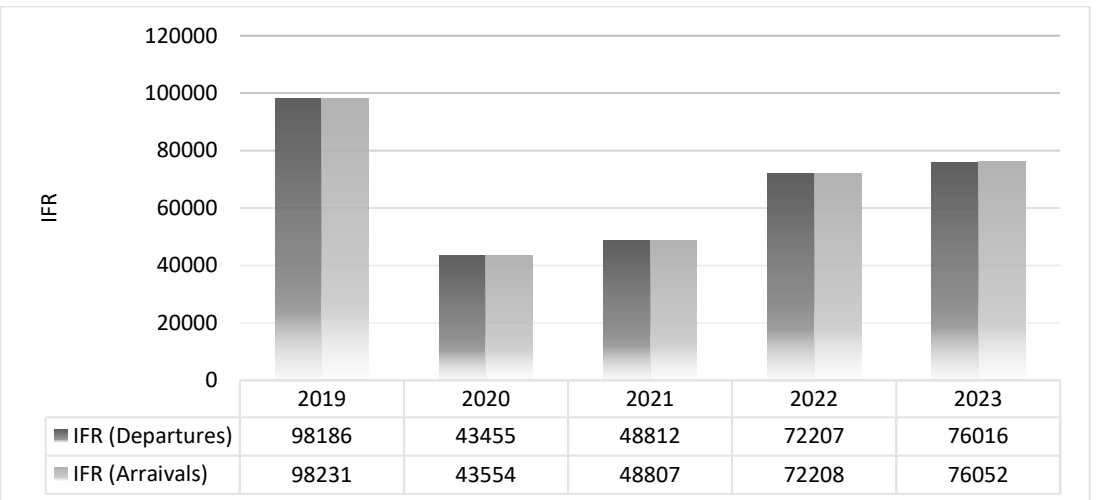


Fig. 1. Dynamics of RPKs and ASKs of Air Baltic airlines

Source: author's elaboration on the basis of Air Baltic, 2020; Air Baltic, 2021; Air Baltic, 2022; Air Baltic, 2023).



	2019	2020	2021	2022	2023
IFR (Departures)	98186	43455	48812	72207	76016
IFR (Arraivals)	98231	43554	48807	72208	76052

Fig. 2. Baltic air traffic movements by instrument

Source: author's elaboration on the basis of (Aviation Intelligence Unit Portal, 2024).

quality services. Investments in smart technologies such as artificial intelligence, big data analytics, and blockchain are crucial for fostering innovation and ensuring competitiveness.

Riivo Tuvike, the CEO of Tallinn Airport, stated that the unique challenges faced by the aviation industry in recent years have underscored the need to focus more on increasing non-aviation revenues. Over-reliance on aviation income poses a vulnerability risk. As a small airport on the periphery of Europe with a small population and significant pressure from airlines, the scope for increasing aviation revenues is limited. Boosting non-aviation revenues is essential (Tuvike, 2023) to safeguard the aviation business. According to Riga Airport's financial report for the first half of 2023, revenues from non-aviation services increased by 60 per cent compared to the first half of 2022, indicating a high demand for non-aviation services.

The Baltic air transport sector currently prioritises infrastructure development and non-aviation services to achieve greater resilience to economic fluctuations. However, more investments in digitisation and advanced technologies are necessary to make the sector more competitive and efficient in the future.

2. Research methods

Based on the analysis of scientific literature, the following key evaluation indicators have been identified to assess the resilience of the air transport sector: RPK, which indicates actual air transport demand, ASK, IFR movements, and employment (EMP).

To evaluate the resilience of the Baltic air transport sector to economic crises, an empirical study was conducted using the Pearson correlation coefficient, multi-criteria evaluation (SAW and TOPSIS), and exponential smoothing methods. The following structural units were chosen for the assessment: airports, air carriers, and air traffic.

2.1. Pearson correlation coefficient

The Pearson correlation coefficient measures the linear relationship between two variables.

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y)^2 - (\sum y)^2]}} \quad (1)$$

Here: r is the correlation coefficient; n is the number of data pairs; ∑xy is the sum of the product of the two variables; ∑x is the sum of the values of the first variable; ∑y is the sum of the values of the second variable; $\sum x^2$ is the sum of the squares of the values of the first variable; $\sum y^2$ is the sum of the squares of the values of the second variable.

The purpose of the Pearson correlation coefficient is to determine the relationship between the RPK and ASK data of "Air Baltic", the sole national airline in the Baltic countries, which is particularly important for assessing the recovery of the air transport sector after the COVID-19 pandemic.

2.2. SAW Method

SAW method calculates the sum Sj of the weighted normalised values of all indicators for each j-th object (alternative).

$$S_j = \sum_{i=1}^{m} w_i \bar{r}_{ij} \quad (2)$$

here: w_i is the weight of the of the i– th indicator; $\bar{r}_{ij}$ — the normalised value of the i-th indicator for the j-th object. The initial data, if the criterion is minimising, is normalised according to the formula:

$$\bar{r}_{ij} = \frac{\min\limits_j r_{ij}}{r_{ij}} \quad (3)$$

here: $\bar{r}_{ij}$ — the value of the i-th criterion for the j-th alternative.

If the criterion is maximising, it is normalised according to the formula:

$$\bar{r}_{ij} = \frac{r_{ij}}{\max\limits_j r_{ij}} \quad (4)$$

2.3. TOPSIS Method

TOPSIS method calculates the distance from the ideal negative and ideal positive solutions. Since equal weights are assigned to all criteria, the first step involves normalising the matrix according to the formula:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (5)$$

Next, we calculate the weighted matrix using the formula:

$$v_{ij} = w_j n_{ij} \ for\ i = 1, \dots, m; j = 1, \dots, n, \quad (6)$$

here: w_j — is the weight of criterion j.

The next step is to calculate the ideal positive and ideal negative solutions using the formula:

$$V^{+} = (v_1^{+}, v_2^{+}, \dots, v_n^{+}) = \left(\left(\max_i v_{ij} \middle| j \in I \right), \left(\min_i v_{ij} \middle| j \in J \right) \right); \quad (7)$$

$$V^{-} = (v_1^{-}, v_2^{-}, \dots, v_n^{-}) = \left(\left(\min_i v_{ij} \middle| j \in I \right), \left(\max_i v_{ij} \middle| j \in J \right) \right), \quad (8)$$

Where I is identified with the maximising criterion and J with the minimising criterion, i = 1, ... m; j = 1, ... , n.

The distances between the ideal positive and ideal negative solution are then calculated using the formula:

$$S_i^{+} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_i^{+} \right)^2}, \ i = 1, 2, \dots, m; \quad (9)$$

$$S_i^{-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_i^{-} \right)^2}, \ i = 1, 2, \dots, m. \quad (10)$$

The relative closeness to the ideal positive solution is then calculated using the formula:

$$P_i = \frac{S_i^{-}}{S_i^{-} + S_i^{+}}. \quad (11)$$

The final step involves ranking the objects under investigation.

The objective of the multi-criteria assessment is to develop a coherent framework of indicators and apply it practically to evaluate the resilience of the Baltic air transport sector to economic crises.

Exponential Smoothing Method

The exponential smoothing method is employed for time series forecasting.

$$S_t = \alpha x_t + (1 - \alpha) S_{t-1} \quad (12)$$

Here: St is the smoothed data point at time t; α is the smoothing factor between 0 and 1; Yt is the true data point at time t; $1S_{t-1}$ is the previous smoothed data point.

The percentage change for each year is then determined in order to objectively assess and represent the rate of change.

The exponential smoothing method aims to identify future projections for the Baltic air transport sector, the analysis of which would allow the sector to be assessed for its resilience to economic crises.

3. Research results

Based on the literature analysis, the following key indicators have been identified to assess the resilience of the Baltic air transport sector to economic crises: RPK, ASK, IFR, and EMP.

The Pearson correlation coefficient is used to determine the relationship between RPK and ASK. Since the Baltic countries have only one national airline, "Air Baltic", which is based in Latvia, only the data from this airline are evaluated. The correlation coefficient between RPK and ASK is close to 1, indicating a very strong relationship between the analysed data. This means that as one variable increases or decreases, the other variable tends to increase or decrease at a very similar rate. This result demonstrates that "Air Baltic" effectively converts available seat capacity into revenue, indicating profitable operations. It also reflects a good pricing strategy and efficient route management, with destinations that meet consumer expectations. It is evident that the company is successfully handling the external factors induced by the COVID-19 pandemic.

The chosen multi-criteria SAW method calculates the assessment score by adding the normalised values of the criteria multiplied by their weights. It is assumed that all indicators are equally important and equal weights are assigned. All values are maximising. The results obtained using the SAW method are as follows (Table 3).

The results indicate that the year 2019 had the highest overall score. However, 2023 shows the highest results in almost all areas, with the RPK indicator being particularly high, suggesting that the demand for flights has returned to pre-pandemic levels. 2023 is identified as a year of recovery for the air transport sector. The TOPSIS method was also applied to ensure objectivity and a more accurate evaluation (Table 4).

The TOPSIS method calculates the distance to the ideal point, and according to this method, the year 2023 is closest to the ideal point. This indicates that the air transport sector performed successfully this year.

Both the SAW and TOPSIS methods show that 2020 was the most challenging year for the air transport sector due to the pandemic. However, by 2023, the sector had recovered and, according to some indicators, even surpassed pre-pandemic levels.

Using the SAW and TOPSIS methods, the years have been ranked to demonstrate the pace of recovery after COVID-19 (Fig. 3).

The study conducted using the SAW and TOPSIS methods allows for a systematic evaluation of the impact of different indicators on the overall air transport sector. Although some individual indicators show that the results for 2023 exceed those of 2019, when the years are ranked according to both meth-

Tab. 3. Results obtained by the SAW method for each indicator separately

Year	RPK	ASK	EMP	IFR Departures	IFR Arrivals
2019	0.284	0.260	0.208	0.290	0.290
2020	0.072	0.098	0.160	0.128	0.129
2021	0.107	0.139	0.174	0.144	0.144
2022	0.223	0.218	0.218	0.213	0.213
2023	0.314	0.284	0.240	0.224	0.224

Tab. 4. Assessing the resilience of the Baltic air transport sector to economic crises using TOPSIS

Year	RPK	ASK	EMP	IFR Departures	IFR Arrivals
2019	0.876	0.871	0.594	1.000	1.000
2020	0.000	0.000	0.000	0.000	0.000
2021	0.145	0.224	0.181	0.098	0.096
2022	0.625	0.645	0.722	0.525	0.524
2023	1.000	1.000	1.000	0.595	0.594

Tab. 5. Projected realistic scenario

	2024	2025	2026	2027
RPK	6025.22	6932.2	7513.13	8150.55
ASK	7986.53	8983.9	9632.18	10340.14
Employment	5759.40	6188.76	6523.27	6874.39
IFR (Departures)	69983.88	74186.61	74116.13	74746.16
IFR (Arrivals)	69992.5	74184.59	74104.29	74724.5

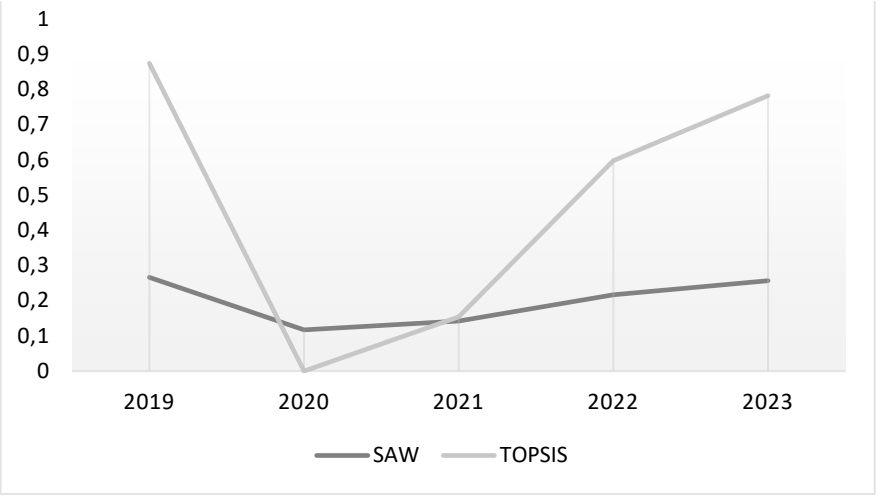


Fig. 3. Recovery rates after COVID-19

ods, 2019 still remains higher, indicating that the Baltic air transport sector has not yet returned to pre-pandemic levels in 2023.

The evaluation reveals a clear recovery following the economic crisis of 2020, indicating that the sector is moving in the right direction. Based on the obtained scores, the Baltic air transport sector should continue to monitor and analyse which operational areas contributed most to this success and adapt their strategies to remain resilient against future economic crises.

The following realistic scenario was obtained using the exponential smoothing method for forecast calculations (Table 5).

To further evaluate and objectively represent growth rates, the percentage change in the forecast was calculated (Fig. 4).

Fig. 4. Annual percentage change in the forecast

The Baltic air transport sector is implementing a growth strategy by increasing the number of passengers and available seat capacity. Such positive growth figures may indicate an optimistic market development scenario. Rising ASK and RPK values require careful management of operational capabilities to maintain optimal seat occupancy levels and avoid excess seat capacity.

The increasing number of employees indicates that the sector is investing in human resources. However, it is important to ensure that the growth in the workforce aligns with demand and does not exceed the necessary efficiency levels. Forecasts of IFR data suggest that the sector anticipates stability in its international flights. This could be a strategic decision that should be analysed considering market trends, competition, and geopolitical factors.

4. Discussion of the results

The assessment of the resilience of the Baltic air transport sector to economic crises aligns with findings from previous studies on the resilience of air transport systems. Resilience, as highlighted by Martin et al. (2015), encompasses the ability to recover and the capacity to adapt and thrive in new realities. Our study confirms this by showing that the Baltic air transport sector has implemented strategies focusing on both aviation and non-aviation services, echoing similar findings by Cook et al. (2023), who emphasised the role of diversification in strengthening sector resilience.

The recovery patterns identified in this study, particularly the strong correlation between RPK and ASK indicators, are consistent with observations by Gabriel Bae et al. (2021), highlighting the importance of effective supply-demand management in enhancing operational efficiency during crises. Moreover, this study's results regarding the increasing emphasis on infrastructure development and direct flights align with Su et al. (2023), who identified similar trends in global air transport recovery post-COVID-19.

The role of sustainability in resilience, as evidenced by the integration of non-aviation services in the Baltic air transport sector, supports the conclusions of Burbidge (2023), who argued that sustainability and resilience are closely interconnected. This study also confirms the findings of Zhong et al. (2024), who emphasised that sustainable practices mitigate economic shocks and enhance adaptability to future crises.

A comparison with Eurocontrol studies reveals parallels in recovery timelines across different crises. For instance, the recovery period observed for the Baltic sector post-COVID-19 mirrors the 1.5-year recovery after the September 11 attacks, as noted by Statfor (2020). However, the economic impact of COVID-19, as shown by the steep decline in RPK (-65.9 %), far exceeds that of previous crises, consistent with findings by the (IATA, 2021).

In terms of methodological contributions, the offered application of multi-criteria evaluation (SAW and TOPSIS) and exponential smoothing methods allows for a structured approach to resilience assessment, aligning with suggestions by Wang et al. (2023) to develop comprehensive quantitative metrics for resilience analysis. These methods, combined with the use of the Pearson correlation coefficients, provide a robust framework for assessing the interconnectedness of key indicators such as RPK, ASK, and EMP.

The importance of non-aviation services as a resilience factor is also consistent with recent trends observed in airport cities, as discussed by Bergantino (2024). This shift towards revenue diversification reflects a global pattern, where airports increasingly rely on retail, parking, and real estate to offset aviation revenue fluctuations.

While this study demonstrates the Baltic air transport sector's progress in recovering from the COVID-19 pandemic, it also underscores the need for further advancements in digitalisation and smart technologies. These findings align with findings by Bakreen et al. (2022), who emphasised the importance of technological innovation in maintaining competitiveness and resilience in air transport.

In summary, this study contributes to the broader understanding of resilience by confirming and expanding upon previous research. The integration of findings from other studies strengthens the argument that resilience is a multidimensional concept, requiring coordinated efforts in sustainability, diversification, and adaptability. Future research should explore the long-term effects of resilience strategies and the role of global interconnectedness in shaping recovery patterns.

Conclusions

The assessment of the resilience of the Baltic air transport sector to economic crises has shown that the sector is transitioning to a new development phase, where the expansion of aviation services alone does not ensure resilience under economic uncertainty. The COVID-19 pandemic demonstrated that offering only aviation services is insufficient for this sector, necessitating a broader spectrum of services. This approach makes air transport businesses more consumer-oriented, attractive to investors and ensures greater stability in uncertain conditions.

A scientific analysis of the resilience of the Baltic air transport sector to economic crises identified key indicators RPK, ASK, EMP, and IFR, which were used to evaluate the sector's performance. The study results showed a strong correlation between RPK and ASK, indicating that Latvia's sole national airline, "Air Baltic", effectively converts available seats into revenue. This is an important indicator that confirms the company's operations are profitable and meet market needs.

The multi-criteria SAW analysis allowed for the examination and comparison of each year's performance based on the mentioned indicators, identifying that 2023 was particularly successful for the air transport sector, and the challenges faced during the pandemic were successfully overcome. This indicates that the sector not only withstood the impact of the COVID-19 crisis but also managed to recover efficiently, which is crucial for sustainable future development.

The TOPSIS method, which evaluates the ideal point, also confirmed that 2023 was the closest to the ideal scenario, demonstrating the best level of sector resilience and effectiveness during the analysed period. These results indicate that the sector can adapt to changing conditions and manage resources efficiently.

The Baltic air transport sector shows that sustainability and resilience to economic crises are closely linked. By integrating sustainability strategies into its operations, the sector successfully withstands economic shocks.

By developing non-aviation services, the sector diversifies its activities, reducing dependency on the cyclicality of aviation and increasing revenue stability.

This study demonstrates that the Baltic air transport sector is on the right track towards achieving sustainability and resilience to economic challenges. However, it is necessary to continue strengthening the technological base and expanding the range of services to ensure the sector's long-term success from a practical point of view.

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Green logistics concept and the impact of its implementation in the organisation: a systematic literature review and meta-analysis

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ABSTRACT
Green logistics aims to minimise its environmental footprint by leveraging advanced equipment and technology while maximising revenue and asset utilisation. This concept is considered a sustainable development approach that can efficiently address environmental challenges without compromising organisational performance or economic growth. Academic literature extensively delves into the concept of green logistics, exploring both theoretical and practical aspects. Many researchers connect green logistics with reducing environmental pollution in the logistics industry through implementing eco-friendly initiatives, new technologies, and innovative practices. However, from a scientific standpoint, the concept currently lacks a systematic understanding. This paper seeks to categorise research related to green logistics and identify future research directions through a systematic literature review and meta-analysis. The research approach employed in this study endeavours to identify the concept, research areas, and implementation perspectives of green logistics. Systematic literature review and meta-analysis enable the authors to comprehensively review recent scientific publications on green logistics, pinpoint existing gaps in the literature, and summarise the key characteristics of the analysed scientific works. Research has demonstrated that the fundamental objective of green logistics is to integrate and coordinate the environmental, social, and economic dimensions of the logistics system to achieve environmentally oriented logistics management. This article makes a significant contribution to the field by providing a comprehensive overview of the current state and evolution of green logistics, emphasising established and emerging areas of interest.

KEY WORDS
green logistics, implementation, systematic literature review, meta-analysis

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Introduction

Logistics activities like transportation, warehousing, packaging, and waste management have positive economic impacts and negative environmental consequences. These activities contribute to global warming through the emission of harmful gases and cause water and air pollution, waste disposal, and fuel consumption. The green logistics concept has been developed to address these issues. Green logistics aims to minimise environmental impact by utilising advanced equipment and technology while maximising revenue and asset utilisation. It is considered

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a sustainable development concept that can help solve environmental problems without compromising organisational performance or the economy (Richnák et al., 2021; Baah et al., 2020; Karaman et al., 2020; Trivellas et al., 2020; Ibrahim et al., 2018; Patra, 2018; Lew et al., 2018; Centobelli et al., 2017; Mckinnon et al., 2015; Sulich et al., 2023).

The green logistics concept has been thoroughly examined in academic literature, addressing theoretical and practical aspects. Research authors often link green logistics with reducing environmental pollution in the logistics industry by implementing eco-friendly initiatives, new technologies, and innovations. These approaches are environmentally beneficial and can potentially increase profitability (Su-Young Kwak et al., 2020; Trivellas et al., 2020; Zowada & Niestrój, 2019; Patra, 2018; Athanasios, 2018; Mckinnon, 2015; Jedlinski, 2014). Sustainable logistics practices involve conserving resources, minimising waste, and enhancing operational efficiency by eliminating redundant processes in logistics operations (Baah et al., 2021; Chhabra et al., 2017).

Kekkonen et al. (2023), Rahman et al. (2020), Jakhar et al. (2019), Cosimato and Troisi (2015), Pazirandeh and Jafari (2013), and Vasiliauskas et al. (2013) noted that green logistics, as a part of the micro-level of social processes, is constantly influenced by societal development, economic and social progress, and environmental initiatives. However, incorporating green logistics practices into traditional logistics operations is challenging. Enhancing the sustainability of logistics processes in operations includes sourcing, transportation, packaging, distribution, warehousing, manufacturing, materials, infrastructure, etc. (Kekkonen et al., 2023; Rahman et al., 2020; Jakhar et al., 2019; Vasiliauskas et al., 2013). The sustainability of a company's logistics processes enhances its competitiveness, betters its image, and yields economic benefits for producers and companies (Rahman et al., 2020).

In scientific terms, the concept of green logistics currently lacks a systematic approach to understanding it. This paper aims to classify the research related to the green logistics concept and identify future research directions through a systematic literature review and meta-analysis. The authors of this scientific paper seek to address the following questions:

RQ1. What is the prevalence of research in green logistics?

RQ2. What is the definition of green logistics?

RQ3. What are the main research fields and implementation perspectives in green logistics?

RQ4. What are the criteria that impact the implementation of green logistics?

1. Research methods for a systematic literature review and meta-analysis of the green logistics concept

A systematic literature review and a meta-analysis were conducted to define the basis of the green logistics concept. The research methods combined, analysed, and summarised data from different studies. A systematic literature review is a process that gathers relevant evidence on a given topic, meeting predefined eligibility criteria, and answers formulated research questions (Baloch & Rashid, 2022; Mengist et al., 2020). Meta-analysis uses statistical methods to summarise data from analysed studies to determine the significance of the topic, provide a more detailed overview of the research on a given topic, and identify current research trends related to the concept of green logistics (Baloch & Rashid, 2022; Ahn & Kang, 2018).

The research approach used in this study aims to identify the concept, research fields, and implementation perspectives of green logistics. The methodology allows the authors to comprehensively review recent scientific publications on green logistics, identify existing gaps in the literature, and summarise the main characteristics of the analysed scientific literature. This includes prevalence in terms of years, country of origin, main keywords, and their co-occurrence.

The study followed the standard PRISMA (Preferred Reporting Item for Systematic Reviews and Meta-Analyses) requirements (Moher et al., 2015; Shamseer et al., 2015). The systematic literature review comprised three stages: initial literature search, extraction and analysis of scientific data, and meta-analysis of selected scientific articles. The primary literature search was conducted using the Scopus bibliographic database. No contact was made with the authors of the publications during the scientific literature search.

The bibliographic data was selected based on specific criteria. These include keywords "green AND logistics", type of publications (scientific articles with open access content), language (English), publication year (2000–2023), and subject area (business, management, and accounting). The following criteria were applied to exclude specific scientific literature:

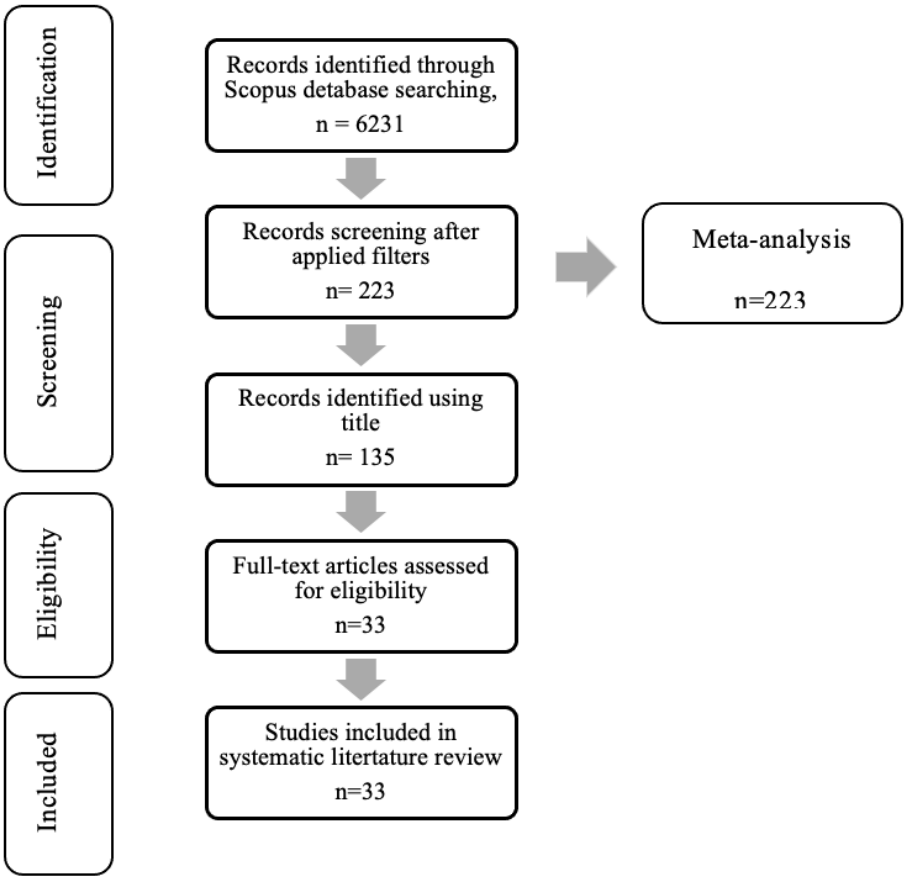

Fig. 1. Publication selection process according to the PRISMA model

articles older than 2000, publications without full-text availability, publications in languages other than English, and publications categorised as systematic literature analysis, meta-analysis, research protocol, or abstract. Additionally, publications that did not correspond to the field of management or logistics were excluded.

The Scopus bibliographic database was initially used to search for scientific literature, which yielded 6231 bibliographic records. After applying the above-mentioned criteria, 223 publications were selected for further analysis. Fig. 1 depicts the structured process of publication selection following the PRISMA model.

2. Research results

2.1. Meta-analysis of the green logistics concept

This section is devoted to a comprehensive analysis of 223 scientific articles sourced from the Scopus database. The detailed examination identifies the leading countries contributing to green logistics research (Fig. 2). Notably, 21.5 % (48) of the selected articles were published in the United Kingdom, followed by China with 14 % (31), Italy, and Sweden each representing 8 % (18), India with 7 % (15), and the United States accounting for 5 % (12).

The data presented in Fig. 2 indicates that the United Kingdom stands out as a prominent leader in green logistics research, amassing an impressive total of 2,374 citations. In contrast, China has emerged as a significant contributor to scholarly publishing in this realm, with a total of 616 citations. This disparity reflects a robust research environment in the UK while also underscoring China's increasing impact on the academic discourse surrounding green logistics, as evidenced by Scopus' open-access publications.

In addition to the contributing countries in the research area, the year of publication and the number of scientific publications were analysed to assess the relevance of the topic in the current context.

Fig. 3 shows a rapid increase in scientific publications on green logistics starting from 2018. This was

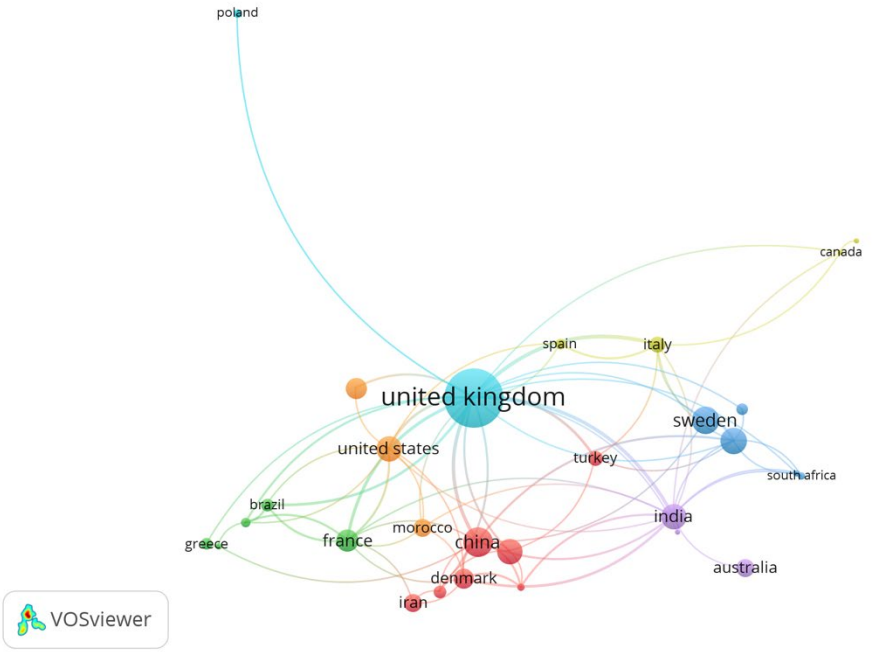

Fig. 2. Bibliographic analysis of scientific data – countries that publish scholarly work

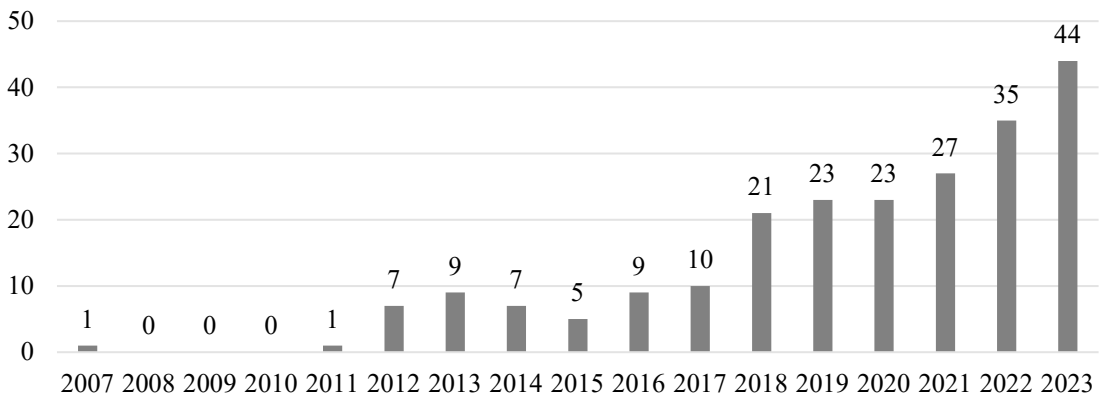

Fig. 3. Bibliographic analysis of scientific data — distribution of publications per year

around the time when the concept of supply chain had already been established in organisations, and the significance of supply chain management was becoming more apparent. Consequently, at that time, explorations commenced of the environmental impact of logistics and potential measures to mitigate it.

Data presented in Fig. 3 infers that green logistics is an increasingly relevant topic in contemporary research, with the number of scientific publications on this topic consistently increasing by 26 % in recent years.

The analysis of the articles found certain most frequent keywords used by the authors (Fig. 4). The VOSviewer software was used to determine the frequency of these keywords, and the circle size in the visual representation indicates the importance of each keyword. Lines connecting the keywords show commonalities, with brighter lines indicating stronger relationships. The distance between keywords signifies the level of cooperation, with closer items representing more intense cooperation. The network is divided into clusters, each represented by a different colour.

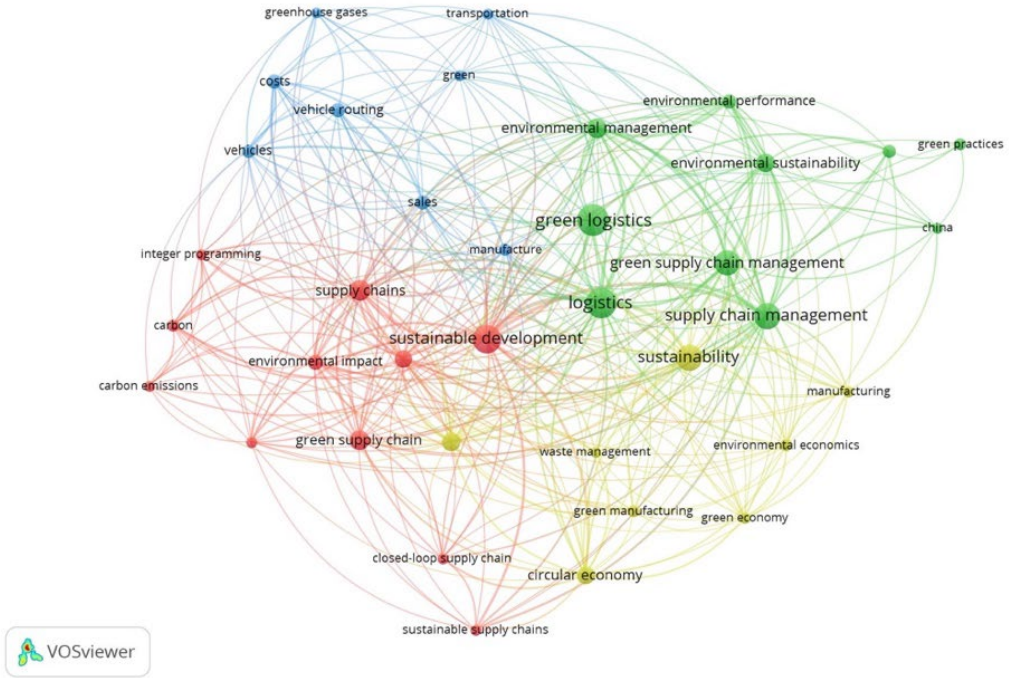

Fig. 4. Co-occurrence of keywords
Source: author's elaboration on the basis of VOSviewer software.

A total of 37 keywords were identified. The most prominent keywords are: "green logistics", "supply chain management", "green supply chain management" (green cluster), "sustainable development", "green supply chain" (red cluster), and "sustainability" (yellow cluster).

The literature on green logistics (green cluster) includes contributions from Baah et al. (2022), Do Carmo Netto et al. (2020), Karaman et al. (2020), Khan et al. (2019), and Lew et al. (2018). Green logistics utilises advanced technology to minimise the environmental impact while maximising revenue and asset utilisation, serving as a sustainable development approach that harmonises ecological concerns with economic performance. Chhabra et al. (2021), Wang (2019), Chhabra et al. (2017), and Cosimato and Troisi (2015), among others, focused on green supply chain management (red cluster), viewing green logistics as a strategy that lessens ecological footprints in goods distribution. It highlights the efficient management of material flows, waste, packaging, and transportation. Boz and Pinto (2024), Hryhorak and Pichugina (2024), Trstenjak et al. (2022), Dzwigo et al. (2021), Frazzon et al. (2019), and He et al. (2017) further investigated green logistics within the context of sustainability and the circular economy (yellow cluster). They regarded it as a crucial aspect of social responsibility that decreases logistics costs while ensuring environmental protection, aligning with corporate social responsibility principles.

In addition, an analysis of co-cited authors (Fig. 5) was conducted, revealing a network of connections among the primary authors of scientific publications on green logistics. Out of 13,797 authors, 87 lead authors were cited at least 18 times. The network consists of five clusters (red — 26 authors, green — 23 authors, yellow — 16 authors, blue — 19 authors, and green — 3 authors), with the most prominent authors being Sarkis (217 citations, 7531 strength of association) and Govindan (121 citations, 4232 strength of association). The strength of the connection attribute indicates the level of association between the co-authors and other researchers.

The theoretical access to the selected 223 articles was analysed using bibliometric methods. This analysis included identifying the most frequently cited authors, the most used keywords in citations, and authors cited overall. Afterwards, a third stage of scientific analysis and synthesis was conducted, involving the evaluation of the title, abstract, and full text of the publications to select articles for further literature analysis. Consequently, 135 scientific articles were selected based on their titles, and 33 articles were selected based on their full text for the systematic literature analysis of the theoretical concept of green logistics.

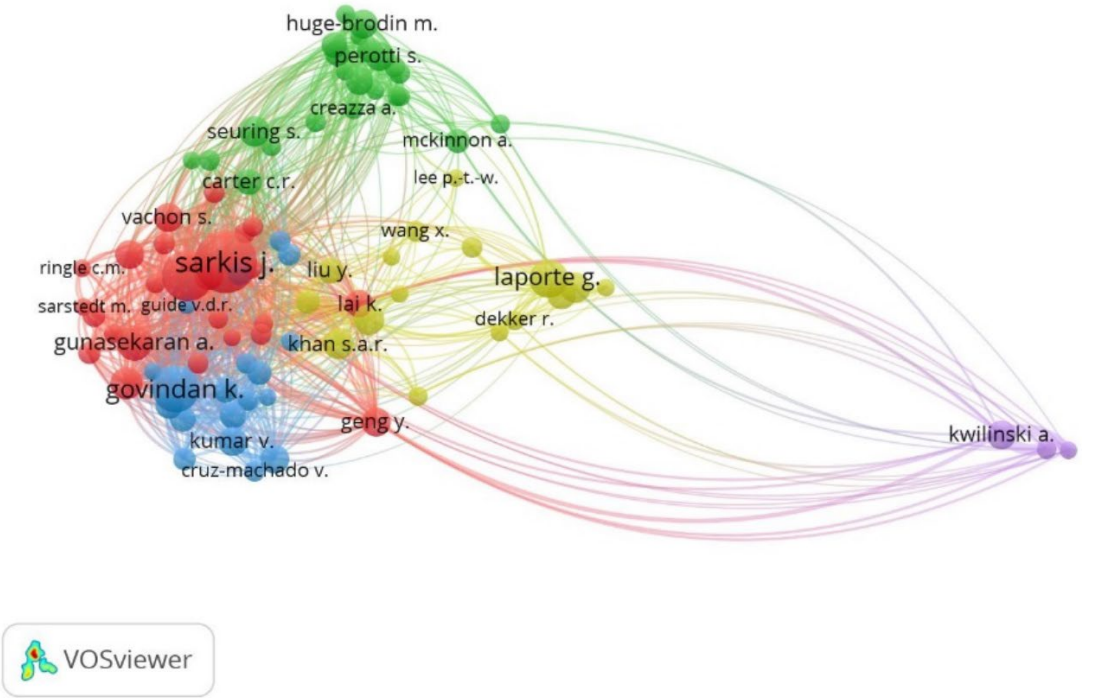

Fig. 5. Co-citation of authors
Source: author's elaboration on the basis of VOSviewer software.

The meta-analysis presented in this section of the paper allows the authors to identify research directions in green logistics, such as green logistics supply chain, green logistics supply chain management, sustainable management, sustainable development, and the circular economy, among others. Further research specifically adopts a systematic literature analysis to enhance the understanding of the green logistics concept.

2.2. Systematic literature analysis of the green logistics concept

The scientific literature recognises that logistics operations generate economic benefits and have detrimental environmental impacts. Activities such as transportation, warehousing, packaging, and waste management utilise facilities that directly contribute to global warming by emitting harmful gases causing the greenhouse effect. Furthermore, these activities result in significant water and air pollution, waste disposal, and fuel consumption. The scientific literature addressing these issues emphasises the importance of green logistics, which involves employing advanced equipment and technology to minimise environmental damage while maximising revenue and asset utilisation. Green logistics is considered a sustainable development concept that can help address environmental problems without compromising the organisation's performance and economy in the exchange of goods and services (Baah et al., 2021; Do Carmo Netto et al., 2020; Karaman et al., 2020; Khan et al., 2019; Lew et al., 2018; Cosimato & Troisi, 2015; Jefimovaitė et al., 2022).

The green logistics concept is complex and has been thoroughly studied from theoretical and practical standpoints. Scientific literature often associates green logistics with reducing environmental pollution in the logistics industry by implementing green initiatives, relevant innovations, and technologies while increasing profitability. Lerher, Pejic and Jereb (2016) considered green logistics a multidimensional discipline that encompasses economic, environmental, and social elements, focusing on actions to reduce harmful environmental impacts and presenting measures and behaviours that contribute to improving society's well-being and economic level. Atmayudha, Syauqi and Purwanto (2021) define green logistics as a logistics activity that emphasises energy efficiency by using energy-efficient means of transport, optimising distribution processes through better routing and scheduling of deliveries, integrating transport processes to reduce the amount of transportation, and using environmentally friendly equipment and vehicles. On the other hand, from the perspective of Kanyepe, Alfaneta and Zizhou (2023),

green logistics is a business approach aimed at reducing the environmental impact of the inventory flow, funds, and related information from the extraction of raw materials to the finished products reaching the end user.

According to Do Carmo Netto et al. (2020), Wang (2019), and Chang and Qin (2009), green logistics involves the planning, organisation, coordination, and control of all logistics operations to achieve customer satisfaction. Furthermore, Chhabra et al. (2022), Wang (2019), Chhabra et al. (2017), Cosimato and Troisi (2015), and Chang and Qin (2009) define four main areas where green logistics principles are actively applied:

- Green logistics product design is crucial as the product designer determines the environmental impact of most products. Sustainable product design involves sufficient use of existing resources, such as cost-effective and environmentally friendly raw materials, rational utilisation of production equipment, and recyclable packaging materials.
- Green transportation involves implementing an environmentally friendly logistics system that aims to minimise pollution during distribution. Modern companies should prioritise reducing environmental impact when planning and implementing their logistics distribution system and operational strategies.
- Green warehousing involves effective warehouse management planning, reducing storage time, and improving freight turnover to enhance logistics efficiency and customer service levels.
- Green packaging promotes the reduction of packaging layers and recycling. The packaging used should be sustainable at all levels, including design, assessment, and construction.

According to De Souza et al. (2022), a green logistics framework has been developed, encompassing green supply logistics, green manufacturing logistics, green sales logistics, and reverse logistics (Fig. 6).

According to Fig. 6, green logistics encompasses a sustainable sourcing process that includes supplier evaluation and selection, and a "green" purchasing and transport process. Green manufacturing logistics refers to ensuring that the product design aligns with green logistics standards and focuses on efficient resource use. This should be continuously improved through enhancements in production management and techniques. The production logistics system must be optimised to reduce energy consumption and waste in material handling, storage, loading, and unloading. Green sales logistics involves intelligently planned sales networks that help optimise transport routes, while the overall transport system aims to make rational and appropriate choices for vehicles and distribution models. Reverse logistics, which operates directly in line with green logistics standards, is key to the entire logistics process.

Navavongsathian et al. (2020) and Klumpp et al. (2010) categorised green logistics into four groups

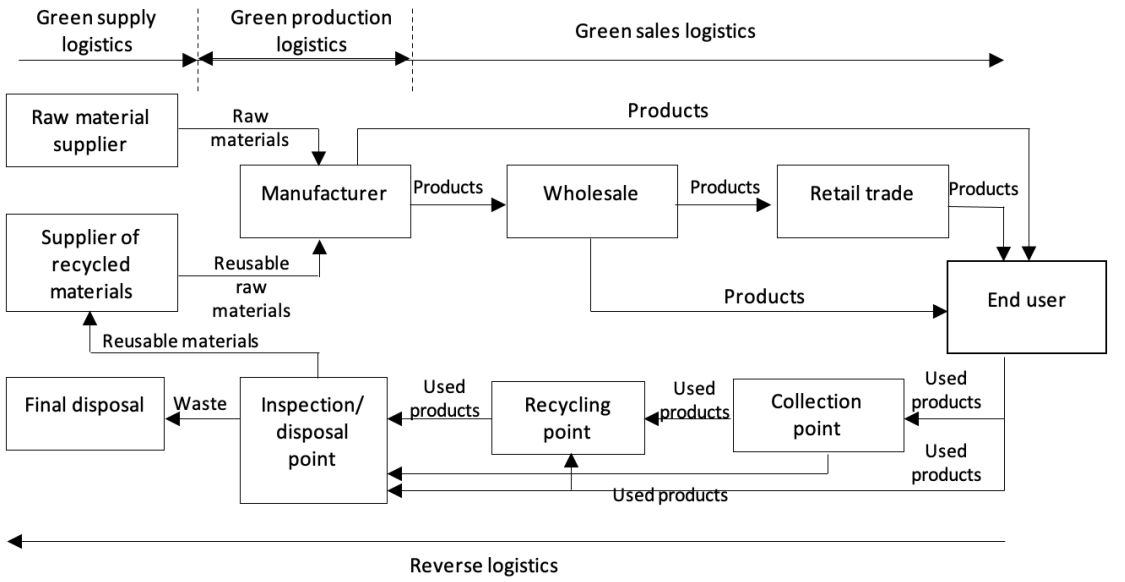

Fig. 6. Green logistics framework
Source: author's elaboration on the basis of (De Souza et al., 2022; Chunguang et al., 2008).

based on research fields and implementation perspectives for integrating green logistics processes.

- Green logistics, from a sustainability perspective, involves the organisation's efforts to achieve a sustainable supply chain performance and the company's responsibility to the community by reducing costs. It includes the cost-effectiveness perspective that focuses on reducing the use of non-renewable materials (such as energy and raw materials), operating environmentally safely, and preventing environmentally harmful events (such as oil spills) and potential injuries to workers. Additionally, the pollution efficiency perspective aims to reduce the emission of greenhouse gases and other pollutants.
- The logistics perspective is based on three key objectives: availability that ensures the right goods at the right place and time; logistics transparency, which provides accurate and real-time information on transport, the status of goods, and the overall performance of logistics to customers and other partners in the supply chain; and quality of the logistics service, addressing the need for intact transport of freight and the smoothness of the logistics service (service-orientation and security awareness).
- Customer perspective covers customer and industry needs, quality, value, and customer expectations. The value perspective addresses the cost ratio and the quality of the goods purchased, which need to be protected and improved. The risk management objective defines the overall risk management approach to avoid situations threatening the enterprise's existence. The process efficiency objective determines the process time and internal process costs to be reduced in supply management, for example, through e-procurement.
- In terms of operational and flexibility perspectives, there are three key factors to consider. First, due to the high frequency of supply chain disruptions and the interference with normal logistical processes, there is a need for speed to respond more quickly to unusual situations and to standardise supply chain events. Second, the increasing technological impact on all steps in the supply chain, individuals, and companies emphasises the need for adaptability, which is the flexibility goal. Finally, the implementation goal recognises that future technologies will require even more education and learning efforts to reach their full potential in supply chain event management, thus posing an implementation barrier.

These perspectives provide an integrated view and allow for adopting green logistics practices, incorporating more sustainable operational logistics solutions. The integration of the green logistics and supply chain management perspectives is illustrated in Fig. 7, which explains that implementing green logistics requires the consideration of four key factors: customer, sustainability, logistics processes, and operational and flexibility perspectives.

Sustainable logistics practices offer the opportunity to conserve resources, reduce waste, and enhance operational efficiency by eliminating unnecessary processes in logistics operations (Do Carmo Netto et al., 2020; Baah et al., 2020; Chhabra et al., 2017). In a broader analysis of the implementation of green logistics, Baah et al. (2020) and Yu (2016) emphasised that this implementation requires a significant investment, particularly in the initial phase, which can impact the financial capacity of companies. However, this investment improves environmental reputation in the long run, ultimately increasing market share and revenues. Aibin et al. (2020) argued that the implementation of green logistics is directly linked to the ecological environment, which must be assessed to promote green logistics. The authors highlight that the sustainable development of logistics activities and the protection of the ecological environment can only be ensured by implementing green logistics. They also state that without the protection of the ecological environment, green logistics activities would not exist.

Meanwhile, Baah et al. (2020) stated that awareness organisations can take a proactive or reactive approach to implementing green logistics practices. The authors explained that a reactive approach involves an organisation limiting its environmental activities to what existing legislation mandates to avoid legal issues. On the other hand, a proactive approach involves voluntary decisions and practices aimed at further reducing negative environmental impacts. Consequently, important factors drive green logistics and influence organisations to either react to or initiate green logistics implementation.

In a study by Bozhanova et al. (2022), the main goal of green logistics is integrating and coordinating environmental, social, and economic aspects within the logistics system. The aim is to achieve environmentally oriented logistics management. The authors conducted a qualitative empirical study to clarify and justify the impact of green logistics on the organisa-

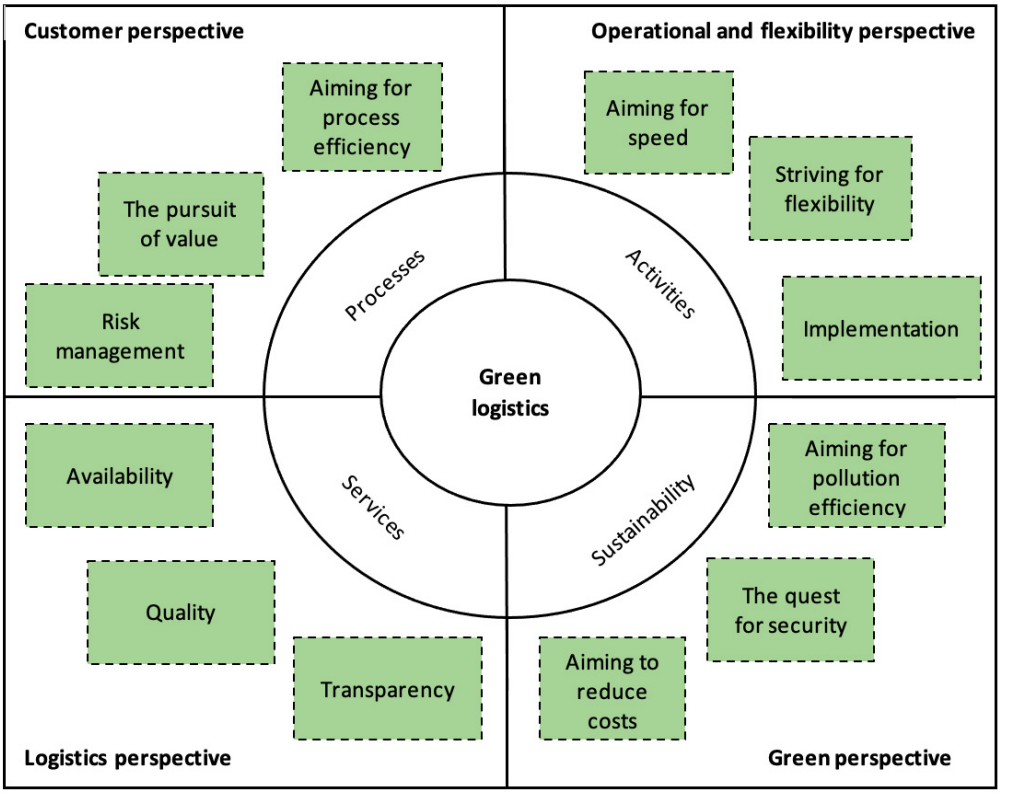

Fig. 7. Perspectives on the Green Logistics System
Source: author's elaboration on the basis of (Navavongsathian et al., 2020; Klumpp & Saur, 2010).

Tab. 1. Impact of implementing green logistics on an organisation and a region

ECONOMIC EFFECT	SOCIAL IMPACT	ENVIRONMENTAL EFFECT
• The increase in Gross Domestic Product (GDP) in absolute terms and per capita due to the expansion of environmental services is particularly decisive for waste management initiatives. • Increases in regional and municipal budgets through income taxes and property taxes. • Introducing fewer polluting technologies and saving resources. • Agricultural and recreational development. • Generating electricity and heat using alternative energy sources.	• Creating new jobs and reducing unemployment. • Declining urban and rural pollution. • Raising awareness. • Developing a caring attitude towards nature.	• Preventing pollution of the atmosphere, soil, and groundwater. • Preserving biodiversity and protecting the environment. • Reducing greenhouse gas emissions. • Saving scarce energy resources and developing alternative energy sources. • Creating an environmentally friendly image of the city and the region.

Source: author's elaboration on the basis of (Bozhanova et al., 2022).

tion and the region in which the logistics activities are carried out, particularly in terms of economic, social, and environmental effects (Table 1).

In a recent study, Dzwigo et al. (2021) proposed that the term "green logistics" should be understood from four scientific perspectives: as a concept for sustainable development of logistics systems at different levels, as a tool for the circular economy, as a component of corporate social responsibility, and as a type of distribution logistics activity. Introducing a mechanism for green logistics can help minimise the costs of managing logistics flows while maintaining an appropriate level of environmental protection, which is crucial for corporate social responsibility,

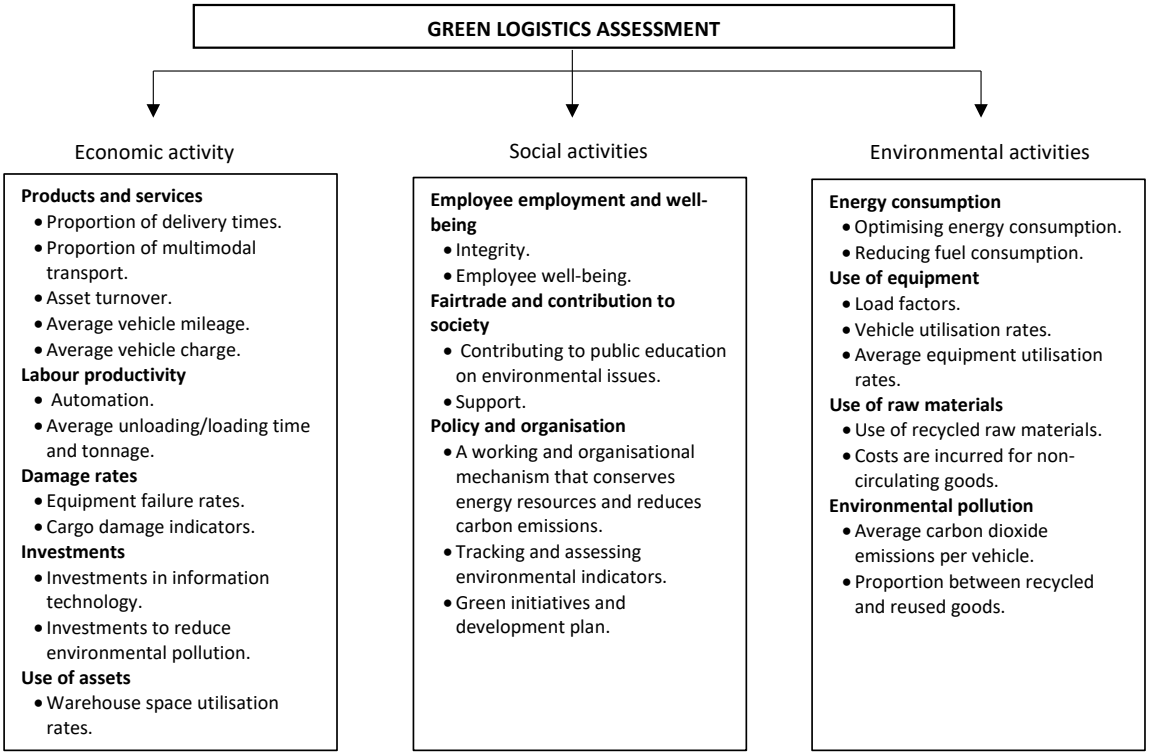

Fig. 8. Green logistics performance evaluation criteria
Source: author's elaboration on the basis of (He et al., 2017).

especially in the context of the circular economy. The authors also outlined the main principles of green logistics (Dzwigo et al., 2021):

- A comprehensive approach to managing logistics flows.
- Rational use of resources involves efficient utilisation of production, finance, energy, and information.
- Minimised use of non-recyclable raw materials and packaging.
- Cost-effective and environmentally friendly transportation and storage of material resources.
- Maximised utilisation of production waste, containers, and packaging to create secondary raw materials or ensure their environmentally friendly disposal.
- Optimised cost of coordinating logistics operations.
- Reduced risk involved in operating transport and logistics systems.
- Raised level of environmental education and staff accountability.
- Introduced innovative technologies to lessen the impact on the environment.
- •Application of information systems and digital technologies to environmental protection.

In a scientific publication by He et al. (2017), the authors clarified the criteria for assessing green logistics performance. These criteria can be associated with the impact of green logistics on the organisation, as analysed by Bozhanova et al. (2022). A consensus is that it is advisable to evaluate green logistics from economic, social, and environmental perspectives (Fig. 8).

As noted by He et al. (2017), the evaluation of green logistics places significant importance on economic performance, with profit being the main objective of logistics. Social performance indicators encompass measures in areas such as education, equity, well-being, access to social resources, health, and charity within a community or region. According to the guidelines provided by He et al. (2017), social performance can be categorised into three dimensions: employment and well-being of workers, fair trade and contribution to society, and policy and organisation. This framework is commonly used to assess logistics performance in the context of low-carbon and sustainable development. The environmental performance of a logistics company essentially defines its social responsibility.

Green logistics integrates environmental goals into traditional logistics operations, encompassing

economic, social, and environmental activities. The success of green logistics showcases a company's ability to protect the environment by conserving natural resources and reducing waste through efficient product flow and storage. It focuses on environmental performance and traditional logistics management goals of cost reduction and increased product value. Currently, green logistics is mostly offered as a value-added service, but it presents an opportunity for companies to gain a competitive edge. There is a visible need to encourage businesses to take the initiative and implement green innovations (Sureeyatanapas et al., 2018).

Green logistics involves incorporating sustainability into the management of logistics and supply chains to minimise environmental impacts, such as greenhouse gas emissions, waste, and energy consumption. Future green logistics research will likely focus on sustainable transport systems, supply chain optimisation, circular economy, and reverse logistics. Additionally, it will emphasise integrating new technologies and sustainable practices to balance operational efficiency and environmental responsibility. This research will also prioritise stakeholder cooperation, improved regulatory frameworks, and better methods for assessing environmental impacts. The future of green logistics will depend on the convergence of technology, policy, and innovative management strategies.

Conclusions

The green logistics concept was defined using a systematic literature review and meta-analysis based on PRISMA requirements. The review involved three steps: an initial search in the Scopus database, selection and analysis of scientific data, and a meta-analysis of selected articles. The analysis encompassed 223 publications. The review found a consistent increase in scientific publications on green logistics, with a 26 % rise in recent years. The most prominent keywords in the publications were "green logistics", "supply chain management", "green supply chain management", "sustainable development", "green supply chain", and "sustainability".

Moreover, a co-cited author analysis revealed linkages between the main authors of green logistics research publications. Out of 13,797 authors, 87 main authors were identified and cited at least 18 times. The selected articles were predominantly published in the UK, China, and Italy.

Green logistics is a sustainable development concept that aims to address environmental issues while facilitating the exchange of goods and services within organisations and across countries. In the scientific literature, green logistics is primarily linked to reducing environmental pollution in logistics operations by implementing green initiatives, innovative technologies, and practices that also contribute to increased profitability.

Green logistics can be categorised into four groups based on the research fields and implementation perspectives for integrating green logistics processes: the sustainability perspective of green logistics, the logistics perspective, the customer perspective, and the operational and flexibility perspective. The primary goal of green logistics is to integrate and coordinate the environmental, social, and economic aspects of the logistics system to achieve environmentally oriented logistics management.

It is suggested that green logistics should be considered from economic, social, and environmental perspectives. Economic performance aims to maximise profits, while social performance involves measures of the well-being of a community or region. Environmental criteria involve an organisation's capability to reduce pollution, manage raw materials, and conserve energy.

The meta-analysis and systematic literature review identified additional research directions for green logistics. Future efforts are likely to focus on sustainable transportation systems, supply chain optimisation, circular economy, and reverse logistics. It will prioritise integrating new technologies and sustainable practices for operational efficiency and environmental responsibility. Additionally, there will be an emphasis on stakeholder cooperation, improved regulatory frameworks, and better methods for assessing environmental impacts, all underpinned by the convergence of technology, policy, and innovative management strategies.

This study has several limitations. First, it relied exclusively on the Scopus bibliographic database as its data source. Second, the systematic literature review was conducted using only 33 open-access articles. Future research would benefit from expanding the number of databases and academic journals included to achieve more comprehensive results in green logistics. Additionally, it could incorporate conference papers, book chapters, review articles, and books as they could enhance generalisability.

Notwithstanding the limitations mentioned above, the study opens a space for discussion.

It makes a significant contribution to advancing research on the concept of green logistics and its implementation perspectives, the results of which are of great relevance to business managers, practitioners, policymakers and other stakeholders looking for an effective transition to green logistics.

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Modelling problems in a regional labour market in Poland with MARS and CMARS — supported by optimisation

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ABSTRACT

The study mainly aims to learn about job candidates' characteristics that influence the declared levels of their general skills *(G).* The set of characteristics examined included common skills *(C),* professional skills *(P)* and other economic and social characteristics of candidates. In this context, it is essential to observe the required knowledge and core skills on the market and to make this knowledge available to decision-makers from public institutions, entrepreneurs and educational institutions. The main research objective is also related to verifying the method used to analyse large multi-dimensional databases of competencies that can be used to improve vocational education and its fit to the labour market. An additional objective of the study is also to find the relationship between the characteristics of the offers (the time of visibility and publication of offers, the distance of the job from the place of residence) and the grouping of competencies in individual professions and occupational groups. It is linked to another problem: identifying factors that influence the design and availability of employee competencies. MARS and CMARS methods were used as neutral computing methodologies to determine the relationship between the response variable *(G)* and the input variables. Their use allows for commenting on how fulfilment can be determined between the requirements of employers and decision-makers in government. The duration of visibility and publication of the offer might be informative for job candidates and, thus, significantly influence the development of competences in the region. The innovative use of advanced statistical methods to achieve the goal in the area of competence management allows for high precision of the results, reducing risks in making management decisions.

KEY WORDS

competence management, conic optimisation, multivariate adaptive regression splines, interior point method, green skills, digital skills

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Introduction

The "fourth revolution" caused by the creation and introduction of new technologies, the internet, the internet of things, computing clouds, interpersonal communication and machines, including cyber-physical systems (Lee et al., 2015), forces employees to continuously develop their understood competencies, comprehended as knowledge, as skills, and as attitudes (Hellström et al., 2000). Financial resources play an essential role in achieving corporate goals and maximising profits. However, more important skills emerge from the knowledge generated and

Özmen, A., Graczyk-Kucharska, M., Szafrański, M., Goliński, M., Weber, G.-W., Gütmen, S., Włodarczak, Z., Çevik, A., & Broda M. (2025). Modelling problems in a regional labour market in Poland with MARS and CMARS — supported by optimisation. *Engineering Management in Production and Services, 17*(1), 52-65. doi: 10.2478/emj-2025-0005

accumulated by the company in the form of human capital and approaches, organisational procedures, processes, procedures, and norms (Soosay & Hyland, 2008). They help create opportunities to use all of the company's resources.

The contribution aims to work out and develop a mathematical model for the identification, analysis, and further use of the dependencies of selected competence categories among learners in professions, as well as other factors that influence the acquisition of these competencies. One of the competence categories was chosen as the basis for the analyses in this paper. This category includes the general skills *(G)* of learners in occupations. The studies were carried out using the Multivariate Adaptive Regression Splines *(MARS)* and *Conic MARS (CMARS)* methods.

This study introduced models based on Conic Multivariate Adaptive Regression Spline *(CMARS)* as the main achievement; an associated Tikhonov regularisation (TR) (Aster et al., 2018) problem was addressed using conic quadratic programming (CQP) methods (Taylan et al., 2007). The complexity of MARS has been penalised via the so-called TR, which expresses itself and is studied here as a problem of CQP. This results in the development of the novel approach *CMARS* (Weber et al., 2012), which employs continuous, well-structured convex optimisation that enables the application of interior point methods (Roos et al., 1997, 2005) and their codes, e.g., MOSEK (Mosek ApS. A Very Powerful Commercial Software for CQP., n.d.). This allows for the benefit of a more model-based approach founded on mathematical optimisation.

The problem of access to competencies has been present in the European market for a long time. The disparity between the existing competencies among workers and the needs of employers can be attributed to various factors, including the cost of living, transportation costs, and migration patterns (Zierahn, 2013). Recently, this problem has been exacerbated for reasons of digital transformation in the economy, sectoral differentiation related to wage levels, or migration issues (Fischer & Nijkamp, 2021). In many publications, this topic appears, while it does not comprehensively address a systemic solution based on comparing market needs and competency potential based on such large data amounts. Most often, it is related to examining the gap between the offered competencies and skills transferred to students upon graduation from higher education and the requirements of the labour market in a narrow area, e.g., marketing (Stimac & Tanasic, 2023) or in selected areas, e.g., knowledge economy (Muzam, 2023). In addition to selecting individual skill areas, the articles also include an analysis of skill gaps related to the career stage in the career advancement stage (Heimler et al., 2012). Most articles show a skills mismatch problem between the university and the labour market in various directions but rarely use data from the actual labour market (Luo & Teeraporn, 2024). The work also refers to corrective actions, e.g., developing training models that close competency gaps (Alonso-Garca, 2020), rather than actions that precede the creation of gaps, as in the research described in the article.

The article proposes an automated and innovative form of competency modelling, considering data on competency needs among employers and competency profiles of candidates, with a simultaneous proprietary method of reducing competencies to the analysed groups.

In the article, after the introduction, a literature review was conducted, the main purpose of which was to indicate the importance of the competence concept in resource management and to show the problem of competence gaps in the labour market. The research method discusses the development of a mathematical model to analyse and study the relationship of selected categories of competencies among students. Multivariate Adaptive Regression Spline *(MARS)* and conic *MARS (CMARS)* methods were chosen for the study due to the complex number of characteristics analysed. The scope and preparation of the data for the study are also presented. In the results section, the developed model, evaluation criteria, and related features are presented, highlighting the accuracy and stability of the model.

1. Literature review

Most often, the definition of competence includes the concept of "skills", especially in professional skills. Competencies are characteristics of employees that contribute to successful job performance and organisational results. These include knowledge, skills, and abilities, plus their characteristics, such as values, motivation, initiative, and self-control (O'Carroll et al., 2017). Since the term "skills" is used in the term "competence", these terms are often obliterated or applied interchangeably.

The terminological problem is not the only one in competence management. Others include the problem of classifying or grouping competences.

Many glossaries, classifications, and divisions of competences were developed in practice. For instance, in Europe, the European Dictionary of Skills and Competences (DISCO II) of the European Commission (European Dictionary of Skills and Competences (DISCO II), n.d.) is one of the standard glossaries. Other sources list other competence categories such as cross-sectional (Szafrański et al., 2017), key (Szafrański & Goliński, 2015), technological (Astuti et al., 2022), digital (Mattar et al., 2022), instrumental (personal), interpersonal (organisation and communication skills), systemic (transferable skills), behavioural and technical (Palacios-Marqués et al., 2016), personal, professional, and social (Naim & Lenka, 2017) competences.

For many years, scientists have pointed out the necessity of personal development of competences to make it possible for the employee to keep or obtain work (Coll & Zegwaard, 2006). The new economy imposes new requirements closely connected to the acquisition of new competences and, thus, lifelong learning and requalification (The Boston Consulting Group, 2018).

This paper analysed competences divided into general *(G)*, common *(C),* and professional *(P)* categories. This division is very pragmatic, based on the reflection of the actual needs of the labour market. In grouping competences, there is a significant correlation to existing typologies. Some of the similarities include a reference to the separation of, e.g., conceptual (creativity and problem-solving), interactive (communication and negotiation), and technical (making plans and items) competences.

Practice and theory show the dynamic approach to interpreting and using competence divisions. For example, the data-driven method was proposed to automatically extract soft skills from text (Fareri et al., 2021). In another competency analysis, the quantification scheme was used with a mathematical approach (Bohlouli et al., 2017), which can be used to evaluate employees towards optimal job assignment and vocational training or for recruitment processes. Meanwhile, the necessity to support the development of competences both in the area of vocational competences (Lee & Yan, 2019) as well as social competences (Engle et al., 2017) is quite explicit, and the area of research in this issue is still a challenge. Across Europe, employers see skills gaps in the local labour market as a major barrier to achieving business goals (Future of Jobs Report, 2023). Labour shortages and skills gaps in Europe are, among other things, the focus of work by the Directorate-General for Communication, which has identified five important areas for strengthening Europe's labour market potential: supporting underrepresented people to enter the labour market, providing support for skills development, training, and education; improving working conditions; improving fair intra-EU mobility for workers and learners and attracting talent from outside the EU (Tackling labour and skills..., 2024).

Since 2017, the OECD Skills for Jobs database has been in place as a tool for policymakers and practitioners to understand where gaps between skill supply and demand are emerging (OECD Skills for Jobs database, 2025).

The topic is also recognised by The Global Green Skills Report 2023, which identifies trends at the intersection of workforce and sustainability based on the activity of more than 930 million LinkedIn users worldwide (Global Green Skill Report, 2023). Among the many documents related to the labour market, attention can also be drawn to European trends that indicate ongoing challenges to sustainability, as well as opportunities for positive change. New technology can save resources and improve work, but it can also increase the demand for energy and natural resources (Production and consumption, 2024).

More and more companies see the need to get involved in the shaping of soft skills among students at the learning stage. The factors affecting employee competences are of significant importance to the management and human resources; therefore, their mutual dependencies were used to develop the model described in the further part of the article with the use of the *MARS* and *CMARS*.

Today, this type of data is modelled primarily by logistic regression (Cabero-Almenara et al., 2021) using a dichotomous scale. This scale did not match the analysed data, and it was unjustified to recode them into 1–0 variables. Considering the multiplicity of variables and both the nominal data (e.g., the region from which the job applicant comes) and the ordinal data (e.g., the level of acquired skills), methods were selected to build adaptive regression models of many variables. Two modelling methods, namely, *MARS* and *CMARS* algorithms, were selected for further analyses. The advantage of *MARS* and *CMARS* is that they make it easy to interpret the results. *MARS* and *CMARS* methods are applied and compared jointly in the scientific literature only in a few publications (Graczyk-Kucharska et al., 2020, 2022), while *CMARS* is newly introduced in the labour market in this study.

2. RESEARCH METHODS

2.1. MULTIVARIATE ADAPTIVE REGRESSION SPLINES

Multivariate Adaptive Regression Spline *(MARS)* (Friedman, 1991) is a special modelling method which is used for solving regressive and classification problems to find the values of dependent variables based on independent variables (Ju et al., 2021). A special strength that makes *MARS* stand out among other methods is its application, which does not require any special assumptions on the functional connections between dependent and independent variables. It is very useful with large amounts of diverse data (data mining). It establishes a multivariate additive model in a two-stage process: the forward and backward stages (Hastie et al., 2009).

In *MARS*, a denotation is adopted concerning its 1-dimensional piecewise linear BFs (basis functions), which is expressed as follows:

$$c^+(x,\tau) = [+(x-\tau]_+, c^-(x,\tau) = [-(x-\tau)]_+ \quad (1)$$

with $[q]_+ := max\{0, q\}$ *a*nd τ being a univariate knot $(x, \tau \in \mathbb{R})$. Therefore, the basic rules of the application of *MARS* can be described as follows:

- The two one-dimensional BFs show piecewise linearity with a knot τ, and together, they are called a reflected pair.
- As a function of vector $X = (X_1, X_2, \dots, X_l)^T$, the output or response variable is represented Y as:

$$Y = f(X) + \varepsilon, \quad (2)$$

where the vector X demonstrates each input variable or predictor X_v, and the stochastic component ε is the noise term, which is supposed to have 0 mean and a finite variance.

- The aim is to identify the reflected pairs for all inputs X_v $(v = 1, 2, \dots, l)$ with l-dimensional knots $\tau_\mu = (\tau_{\mu,1}, \tau_{\mu,2}, \dots, \tau_{\mu,l})^T$ and input data $\tilde{x}_\mu = (\tilde{x}_{\mu,1}, \tilde{x}_{\mu,2}, \dots, \tilde{x}_{\mu,l})T$ $(\mu = 1,2, \dots, N)$, where N is the number of observations (Hastie et al., 2009; Özmen & Weber, 2014).
- The purpose is to develop a set of 1-dimensional basis functions consisting of all the inputs X_v $(v = 1, 2, \dots, l)$:

$$S := \{[X_v - \tau]_+, [\tau - X_v]_+ \mid \tau \in \{x_{1,v}, x_{2,v}, \dots, x_{N,v}\}, v \in \{1,2,\dots,l\}\}. \quad (3)$$

- Linear combination f (X) is built up based on the set S and takes the form:

$$Y = \beta_0 + \sum_{p=1}^{P} \beta_p T_p(X^p) + \varepsilon, \quad (4)$$

including constant term β_0.

- Given that the input values differ from each other, there are *2Np BFs* as follows:

$$T_p(x_\mu^p) := \prod_{k=1}^{K_p} [m_{\kappa_v^p} \cdot (x_{\mu\kappa_v^p} - \tau_{\kappa_v^p})]_+ \quad (\mu = 1,2,\dots,N) \quad (5)$$

Based on Formula (5), the number of truncated mappings, multiplied within the BF, $x_{a\kappa_b^p}$ is the knot associated with $x_{a\kappa_b^p}$ and $m_{\kappa_b^p}$ denotes a selected sign ±1 (Hastie et al., 2009; Özmen et al., 2014).

2.2. CONIC MULTIVARIATE ADAPTIVE REGRESSION SPLINES

In *CMARS*, where "C" can also be read as Convex and Continuous, the golden middle between accuracy and stability is sought, where stability can also be interpreted by reduced complexity. This idea of maintaining the reasonable complexity level is delivered in two different ways: (i) by keeping the discretised integral of first- and second-order derivatives of the BFs within some tolerance (under some upper bound), and (ii) by using modern optimisation theory along with a model-based approach for more integrated treatment of the *MARS* forward step and its backward step. Therefore, it makes it closer to applying the power of differential and integral calculus and to future developments in calculus and optimisation theory. The complexity of regression and classification tool *MARS* was penalised via the so-called TR, which expresses itself and is studied here as a problem of CQP. This leads to the new method *CMARS* (Taylan et al., 2007), which is more model-based and applies continuous, well-structured convex optimisation that enables the employing of interior point methods (Roos et al., 1997, 2005) and their codes, e.g., MOSEK (Mosek ApS. A Very Powerful Commercial Software for CQP., n.d.).

In *CMARS*, the backward stepwise algorithm of *MARS* is not used to inquire the model *f(x)* in Eq. (2). More detailed characteristics of the method were widely described in the operational research literature (Taylan et al., 2007; Özmen et al., 2011; Weber et al., 2012; Özmen & Weber, 2014).

2.3. Scope and preparation of data for research

At the start of the modelling, the researchers found a big set of data from 2013–2015 with competence characteristics of nearly 20 000 students of technical secondary schools representing several dozen professions and demand for competences from nearly 1 200 companies described with 20 thousands of skills, and additionally, several dozen diverse variables (including time-based ones), describing the competence profile of the students and job offers published by the business owners.

In the first step (ordering the data for analyses), a data structure was made based on their source of origin, i.e., system.zawodowcy.org. It was necessary to specify which type of data can be used. The purpose was to analyse the possibility of using big datasets and data mining analyses to create mathematical and applicational models supporting decision-making for the availability of human resources to improve the competitiveness of the region. The available categories of data from the system which were reviewed are the following: competence, qualification, enterprise, job offer, user skills, skills on the job offer, type of qualification, skills, and users. After the analyses, data categories were created that apply to employers and jobs, internships, and training programme candidates, as well as an example of the type of data in separate categories. In reality, many more data categories exist in the system due to its extensive functionality. Most items belonging to the data categories are linked to one another with at least one attribute, thus creating a very complex network of relations among them.

It must be emphasised that n is 20 000 skills, and every one of those selected by an individual candidate might have been evaluated on a scale of 1 to 5, where 1 means the lowest level of mastering a given skill, and 5 means the highest. The candidates self-assessed the mastering of their skills during classes supervised by teachers. In the case of employers, they estimated skills required for job positions on the same scale — 1 being the lowest and 5 the highest.

The diversity of the entire dataset proved too extensive relative to the capacities of the MARS-support tool available to the researchers; therefore, in the next step, it was necessary to choose a specific data

Tab. 1. Dependent variable and independent variables selected for the applicative mathematical model of general skills (G)

	VARIABLE	SCALE
Student's total evaluation value of general skills for particular offer:	Y_G	1-5
Student's gender:	X_1	1-2
Student's birthday:	X_2	date
Student's competence profile creation date:	X_3	date
Starting time of job offer publication:	X_4	date
Ending time of job offer publication:	X_5	date
Time of commencement of work indicated in the job offer:	X_6	date
Date of creation job offer:	X_7	date
Part-time or full-time employment indicated in the job offer:	X_8	2-5
Type of employment (contract) indicated in the job offer:		1-3
Number of employment positions indicated in the job offer:	X_{10}	1-60
Shift work indicated in the job offer:	X_{11}	1-2
Job offer nonstationary work:	X_{12}	1-2
Compliance of the location between job offer and candidate:	X_{13}	1-2
Student's total evaluation value of common skills for a particular offer: X_C or	X_{14}	1-5
Student's total evaluation value of professional skills for a particular offer: X_P or	X_{15}	1-5

Tab. 2. Numbers of skills from the dictionary in system.zawodowcy.org indicated at least once in the competence profiles of IT specialists in the job, training period and internship offers. Data for the period 01.01.2013 – 31.12.2015.

SKILL CATEGORIES	NUMBER OF SKILLS INDICATED AT LEAST ONCE BY STUDENTS (IT TECHNICIAN) IN THEIR COMPETENCE PROFILES	NUMBER OF SKILLS INDICATED AT LEAST ONCE IN JOB, TRAINING PERIOD, AND INTERNSHIP OFFERS
G	148	109
C	335	444
P	3 324	2 568

group out of the whole set of 20 321 students and 1 206 employers. The data are chosen as follows due to the vastness of the group of variables named skills, according to the competence key, for a representative group of students, competence profiles in the profession of IT technician, as well as due to representativeness, credibility, and reliability of data, and the possibility of changing the quality description to quantity one with respect to variables $x_1,\ldots,x_{15}$ presented in Table 1.

The choice of the profession is based on two criteria. First is the vast demand for competences in the studied region, and second is the biggest sample representing the dataset in the analysed dataset. In this case, the analysis of the possible uses of that dataset for data mining analyses and the creation of applicative mathematical models is most justified. For further analyses, the researchers chose data connected with the profession of the IT technician, which is represented by 2 173 IT technicians in the database. In their competence profiles prepared with the use of the competence dictionary, the students selected from 3 874 skills at least once. Meanwhile, in the job, training programmes and internship offers posted in the system and employers pointed out 3 133 skills at least once in 619 job offers. Despite narrowing the data to the profession of the IT technician, the number and diversity of skills are still too extensive. Table 2 shows how many skills *G, C,* and *P* are pointed out to at least once by 2 173 IT technicians, and how many skills in each category are pointed out to at least once in the job, training programme and internship offers.

It is also worth pointing out the necessity of preprocessing the input, such as dates, city, type of work, and work time, which are significant for the designed data model. The data were going to be used for *MARS* and *CMARS* analyses; therefore, it was necessary to reduce them and transform them into numerical values.

Consequently, to scientifically clarify the aforementioned needs and goals, the article focuses on two modelling approaches which set up a frame to generate the response data as the forward problem: a general and a reduced (simplified) model. Then, the main modelling follows the inverse problem, formulated by optimisation problems, solved by models, and the estimation results. This approach is a part of the novelty work in this paper.

The thousands of skills attributed to student groups and job offers forced the researchers to group them. The data reduction made it possible to analyse the data in the context of all skills in each of the three categories (*G, C*, and *P*) and each relation: competence profile-R-offer, compliance, and gaps in skills when it comes to the needs of employers stemming from job offers and the possibility of their satisfaction by students learning to be IT technicians, via three values x_P ,x_C, y_G. The analysed independent variable *y* refers to skills in the category *G*, which means the examined influence of different independent variables on the shaping of the set of *G* category skills of students learning to be IT technicians, including whether the *G* category set of skills is affected by skill sets in the category *C* and *P*. To reduce the number of dependent variables referring to skills, a generalised model was developed, which was then simplified even more to a simplified model for further analyses. Due to the complexity of the model, its presentation was supplemented with examples.

The data source system.zawodowcy.org contains a list of skills (denoted by *k*), which is based on the core curriculum in vocational education, and which are linked with one of the *G, C* or *P* groups.

Student i has a skill (k) that has been assessed , $\propto_i^k$ e.g., G_1 is assessed at 3, G_2 at 3, G_3 at 5, C_1 at 4, C_2 at 4, P_1 at 2, P_2 at 3, and P_3 at 5. In the offer j, one of the entrepreneurs described job position skills that are required from potential employees. Additionally, employers estimated the significance of how much the chosen skills are needed. The generalised model includes all the data specified in Table 3; however, in the simplified model, the level of the chosen skills required by the entrepreneur β_j^k is skipped.

The compilation of data shows information about similarities and dissimilarities between the expectations of entrepreneurs and the possibilities of the students. Regarding each skill k, it is possible to describe those differences in one value/number which results from the multiplication of two factors in the simplified model (6) and three factors in the generalised model (7) (Table 2):

$$\vartheta_j^k \alpha_i^k \tag{6}$$

$$\vartheta_{ij}^k \alpha_i^k \beta_j^k \tag{7}$$

In this case, the model for calculating the data of the response variable Y_G for a given pair (i, j) looks as follows:

$$y_G = \sum_{k=1}^{K} k \vartheta_j^k \alpha_i^k, \tag{8}$$

$$y_G = \sum_{k=1}^{K} k \vartheta_j^k \alpha_i^k \beta_j^k. \tag{9}$$

In the same way, as the value y_G in Eq. (8) for the simplified model and in Eq. (9) for the generalised model was computed, the values x_c and x_p are calculated. In this case, by summing up multiplications in columns 5 and 6 of Table 3 for competences in category *G*, the total evaluation value about *G* of any given pair *(i,j)* is built. This is shown as the sum (y_G) in Table 3. Analogically, the values for skills in groups *C* and *P* are aggregated and denoted as (x_0) and (x_z), respectively (Table 3). The similarities and dissimilarities in the assessed values in terms of y and x follow from our statistical big data existing in the system, through which the relationships are modelled between general *(G)*, common *(C)*, and professional skills *(P)*, how strongly *C* and *P* impact *G*, and vice versa. In the presented example of the job offer, the sum of values calculated for each group of general skills *G*, a response is treated as a dependent or an output variable. It is a sum of values related to other groups of variables that are treated as predictor, independent, or input variables. For each possible student-offer combination *(i, j)*, the triple (y_G, x_C, x_P) was calculated. An example is presented in Tables 3–4. A programming environment was developed for research, consisting of several Matlab and object-oriented codes.

Tab. 3. Compatibility assessment and gaps between skills developed by student i and requirements of offer j for the simplified model and generalised model

SYMBOL OF SKILLS (*k*)	STUDENTS' ASSESSMENT α_i^k	LEVELS OF CHOSEN SKILLS WHICH ARE REQUIRED BY THE ENTREPRENEUR β_j^k	SIGNIFICANCE FOR ENTREPRENEUR ϑ_{ij}^k	SIMPLIFIED MODEL $\vartheta_j^k \alpha_i^k$	GENERALISED MODEL $\vartheta_{ij}^k \alpha_i^k \beta_j^k$
G_1	3	4	2	6	24
G_2	3	5	2	6	30
G_3	5	-	-	0	0
G_5	-	2	1	0	0
Sum (y_G)				**12**	**54**
C_1	4	-	-	0	0
C_2	4	-	-	0	0
C_3	-	1	1	0	0
Sum (x_C)				**0**	**0**
P_1	2	3	1	2	6
P_2	3	2	2	6	12
P_3	5	-	-	0	0
Sum (x_P)				**8**	**18**

Tab. 4. Couple (i, j) and sums of values for particular categories of skills

COUPLE (*i, j*)	y_G	x_C	x_P
(1, 1)	12	0	8
(1, 2)	32	12	21
⋮	⋮	⋮	⋮
(126, 56)	12	0	3
⋮	⋮	⋮	⋮
(1650, 186)	125	234	0

3. RESEARCH RESULTS

In this *MARS-supported* approach, optimally estimated models with a reduced number of BFs and M_{max} are obtained after a forward and a backward step of *MARS* along its software (SPM 2018). Hereby, a notable benefit is derived from the help of the "generalised cross-validation" *(GCV)* given in Eq. (6), and eventually, the optimal model with the best predictive fit is chosen. At first, with the forward stage of *MARS,* the highest degree of interaction *(M_{max})* and the number of BFs are assigned as 3 and 38, respectively. Then, through the backward stage of *MARS,* the number of BFs is cut down to 22. Herewith, the complexity of the *MARS* model was strongly reduced while its stability was enhanced. Consequently, after these efforts, at the end of the backward stage, the BFs are represented as follows:

$$
\begin{aligned}
BF_1 &= \max\{0, x_4 - 5281\}, & BF_2 &= \max\{0, 5281 - x_4\},\\
BF_3 &= \max\{0, x_6 - 5292\}\cdot BF_1, & BF_4 &= \max\{0, 5292 - x_6\}\cdot BF_1,\\
BF_5 &= \max\{0, x_{14} - 0\}\cdot BF_4, & BF_7 &= \max\{0, 4 - x_{15}\},\\
BF_8 &= \max\{0, x_{11} - 1\}\cdot BF_7, & BF_{11} &= \max\{0, x_6 - 5431\}\cdot BF_8,\\
BF_{12} &= \max\{0, 5431 - x_6\}\cdot BF_8, & BF_{14} &= \max\{0, 5296 - x_6\}\cdot BF_7,\\
BF_{15} &= \max\{0, x_6 - 5115\}\cdot BF_2, & BF_{16} &= \max\{0, 5115 - x_6\}\cdot BF_2,\\
BF_{18} &= \max\{0, 5752 - x_5\}\cdot BF_7, & BF_{19} &= \max\{0, x_6 - 5407\}\cdot BF_8,\\
BF_{21} &= \max\{0, x_{14} - 0\}\cdot BF_2, & BF_{22} &= \max\{0, x_4 - 5320\}\cdot BF_8,\\
BF_{23} &= \max\{0, 5320 - x_4\}\cdot BF_8, & BF_{24} &= \max\{0, x_4 - 5269\}\cdot BF_8,\\
BF_{26} &= \max\{0, x_4 - 5395\}\cdot BF_8, & BF_{28} &= \max\{0, x_6 - 5176\}\cdot BF_7,\\
BF_{30} &= \max\{0, x_4 - 5395\}\cdot BF_{28}, & BF_{34} &= \max\{0, x_4 - 5377\}\cdot BF_{28},\\
BF_{36} &= \max\{0, x_4 - 5403\}\cdot BF_{28}, & BF_{38} &= \max\{0, x_6 - 5187\}\cdot BF_8.
\end{aligned}
\tag{10}
$$

The optimal *MARS* model with the BFs above is presented in the subsequent form:

$$
\begin{aligned}
\hat{Y} = \beta_0 + \sum_{m=1}^{M} \beta_m T_m(\boldsymbol{X}^m) = {} & -5.076 + 0.0017\cdot BF_3 + 0.0056\cdot BF_4 + 0.00014\cdot BF_5\\
& + 8.917\cdot BF_7 + 43.130\cdot BF_8 - 3.086\cdot BF_{11} - 0.230\cdot BF_{12} - 0.0405\cdot BF_{14} + 0.0015\cdot BF_{15}\\
& + 0.012\cdot BF_{16} + 0.010\cdot BF_{18} + 2.363\cdot BF_{19} + 0.005\cdot BF_{21} - 2.051\cdot BF_{22} + 0.152\cdot BF_{23}\\
& + 1.025\cdot BF_{24} + 1.475\cdot BF_{26} + 0.055\cdot BF_{28} - 0.031\cdot BF_{30} + 0.0094\cdot BF_{34} + 0.021\cdot BF_{36}\\
& - 0.235\cdot BF_{38}.
\end{aligned}
\tag{11}
$$

Random variables are congruent with the description in Table 2. For the *CMARS* model, the offer visible from *(x_4)*, the job offer visible to *(x_5)*, the offer date of work *(x_6)*, the offer of shift work *(x_{11})*, a student's total evaluation value of common skills for the particular offer X_C *(x_{14})*, and a student's total evaluation value of professional skills for the particular offer x_p *(x_{15})* are significant. Here, all of the parameter values estimated for the *MARS* model are represented in Table 2. In consequence, six inputs have effects on the response variable among 15 variables within our *MARS* model. Here, three of these six inputs are regarded as time. Thus, it means that three of our six time-variables (Table 2) are included in the *MARS* model. This proves that this model has a high time dependence.

In the *CMARS*, which is optimisation-supported, estimated models with the maximum number of *BFs, $M_{max,}$* are constructed after a forward step of *MARS* along its software (SPM, 2018). Hereby, a notable benefit is derived from the help of the *PRSS* and *CQP* given in Eq. (8) and Eq. (9), and eventually, the optimal model with the best predictive fit is chosen. At first, with the forward stage of *MARS*, the highest degree of interaction *(M_{max})* and the number of BFs are assigned as three and 38, respectively. The complexity of *MARS* is penalised via the so-called TR, which expresses itself

and is studied here as a problem of *CQP*. Herewith, the complexity of the *MARS* model was reduced while its stability was enhanced. Consequently, after these efforts, at the end of the forward stage, the BFs are represented as follows:

$$
\begin{aligned}
&BF_1 = \max\{0, x_4 - 5281\}, && BF_2 = \max\{0, 5281 - x_4\},\\
&BF_3 = \max\{0, x_6 - 5292\} \cdot BF_1, && BF_4 = \max\{0, 5292 - x_6\} \cdot BF_1,\\
&BF_5 = \max\{0, x_{14} - 0\} \cdot BF_4, && BF_6 = \max\{0, x_{15} - 4\},\\
&BF_7 = \max\{0, 4 - x_{15}\}, && BF_8 = \max\{0, x_{11} - 1\} \cdot BF_7,\\
&BF_9 = \max\{0, x_5 - 5715\} \cdot BF_8, && BF_{10} = \max\{0, 5715 - x_5\} \cdot BF_8,\\
&BF_{11} = \max\{0, x_6 - 5431\} \cdot BF_8, && BF_{12} = \max\{0, 5431 - x_6\} \cdot BF_8,\\
&BF_{13} = \max\{0, x_6 - 5296\} \cdot BF_7, && BF_{14} = \max\{0, 5296 - x_6\} \cdot BF_7,\\
&BF_{15} = \max\{0, x_6 - 5115\} \cdot BF_2, && BF_{16} = \max\{0, 5115 - x_6\} \cdot BF_2,\\
&BF_{17} = \max\{0, x_5 - 5725\} \cdot BF_7, && BF_{18} = \max\{0, 5752 - x_5\} \cdot BF_7,\\
&BF_{19} = \max\{0, x_6 - 5407\} \cdot BF_8, && BF_{20} = \max\{0, x_7 - 5407\} \cdot BF_8,\\
&BF_{21} = \max\{0, x_{14} - 0\} \cdot BF_2, && BF_{22} = \max\{0, x_4 - 5320\} \cdot BF_8,\\
&BF_{23} = \max\{0, 5320 - x_4\} \cdot BF_8, && BF_{24} = \max\{0, x_4 - 5269\} \cdot BF_8,\\
&BF_{25} = \max\{0, 5269 - x_4\} \cdot BF_8, && BF_{26} = \max\{0, x_4 - 5395\} \cdot BF_8,\\
&BF_{27} = \max\{0, 5395 - x_4\} \cdot BF_8, && BF_{28} = \max\{0, x_6 - 5176\} \cdot BF_7,\\
&BF_{29} = \max\{0, 5176 - x_6\} \cdot BF_7, && BF_{30} = \max\{0, x_4 - 5395\} \cdot BF_{28},\\
&BF_{31} = \max\{0, 5395 - x_4\} \cdot BF_{28}, && BF_{32} = \max\{0, x_4 - 5408\} \cdot BF_{28},\\
&BF_{33} = \max\{0, 5408 - x_4\} \cdot BF_{28}, && BF_{34} = \max\{0, x_4 - 5377\} \cdot BF_{28},\\
&BF_{35} = \max\{0, 5377 - x_4\} \cdot BF_{28}, && BF_{36} = \max\{0, x_4 - 5403\} \cdot BF_{28},\\
&BF_{37} = \max\{0, 5403 - x_4\} \cdot BF_{28}, && BF_{38} = \max\{0, x_6 - 5187\} \cdot BF_{28},\\
&BF_{39} = \max\{0, 5187 - x_6\} \cdot BF_{28}, && BF_{40} = \max\{0, x_5 - 5271\} \cdot BF_{28}.
\end{aligned}
\tag{12}
$$

The optimal CMARS model with the BFs above is presented in the subsequent form:

$$
\begin{aligned}
\hat{Y} = \beta_0 + \sum_{m=1}^{M_{\max}} \beta_m T_m(\boldsymbol{X}^m) = {} & -5.7471 - 0.1029 \cdot BF_2 - 0.0203 \cdot BF_3 + 0.0020 \cdot BF_4 + 0.0063 \cdot BF_5 + 0.00014 \cdot BF_6\\
& + 0.0102 \cdot BF_7 + 0.0015 \cdot BF_8 + 0.0024 \cdot BF_9 - 0.0071 \cdot BF_{10} - 0.0034 \cdot BF_{11} - 2.1519 \cdot BF_{12} - 1.6404 \cdot BF_{13}\\
& - 0.0571 \cdot BF_{14} + 0.0360 \cdot BF_{15} + 0.0018 \cdot BF_{16} + 0.0011 \cdot BF_{17} + 0.014 \cdot BF_{18} + 1.099 \cdot BF_{19} + 1.553 \cdot BF_{20}\\
& + 0.005 \cdot BF_{21} - 0.987 \cdot BF_{22} - 1.138 \cdot BF_{23} + 0.704 \cdot BF_{24} + 0.431 \cdot BF_{25} + 0.849 \cdot BF_{26} + 0.878 \cdot BF_{27}\\
& + 0.00005 \cdot BF_{28} - 0.086 \cdot BF_{29} - 0.016 \cdot BF_{30} - 0.016 \cdot BF_{31} - 0.0019 \cdot BF_{32} - 0.0011 \cdot BF_{33} + 0.005 \cdot BF_{34}\\
& + 0.004 \cdot BF_{35} + 0.0127 \cdot BF_{36} - 0.0131 \cdot BF_{37} - 0.0858 \cdot BF_{38} - 0.1595 \cdot BF_{39} + 0.000006 \cdot BF_{40}.
\end{aligned}
\tag{13}
$$

Random variables for our *CMARS* model are congruent with the description in Table 2, the same as for our *MARS* model. In consequence, six inputs have effects on the response variable among 15 variables within the *CMARS* model. Thus, it means that three of our six time-variables (Table 2) are included in the *CMARS* model like in the MARS model.

Some of the most essential measures of statistical performance assessment and statistical comparison were used, as represented in Table 5.

Herewith, Average Absolute Error (AAE), Root Mean Square Error (RMSE), Multiple Coefficient of Determination (Adjusted R^2), and Correlation Coefficient *(r)* were addressed as the measurements of the accuracy to measure the predictive capability of each model. Therefore, the accuracy criteria show which model has a superior predictive ability to others and which is the best.

Here, adjusted R^2 likewise R^2 reflects the amount of data falling within the line or the regression curve. However, while R^2 presumes that every regarded variable explains the variation in the response variable, the adjusted R^2 provides the percentage of variation explained by those independent variables that affect the response variable. Moreover, adjusted R^2 causes a penalisation for adding independent variables which do not fit the model. Herewith, it suits this study with its use of generalised cross-validation or, in terms of optimisation theory, Tikhonov regularisation.

As far as the closeness to linearity is concerned, *MARS* models belong to the "nearest" elements on

the portfolio of model classes since, eventually, in any single dimension or variable, *MARS* is based on piecewise linear functions. Nonlinearity only enters into the *MARS* model through the multiplication of those 1-dimensional basis functions, which has to serve for a more accurate and sufficiently stable data fitting. Hereby, the number of multiplications in *MARS* can be controlled by a (hyper-) parameter, which is the "maximal degree of interaction".

The measure *r* is the standardised regression coefficient beta of one variable by another (and vice versa), and it assesses the size of the mutual effect. This is rather clearly observed whenever the variables are dichotomous. In fact, *r* is very helpful when a priori investigating multi-dimensional data by pairs of variables and scatterplots of the (projected) data and figuring out some approximate linear dependencies. These scatterplots can be a modelling help for *MARS* by identifying areas ("regimes") of linear dependence and, overall, understanding the underlying piecewise structure of the *MARS* model. All of this can become a part of a GUI (Graphical User Interface), which aims to make it convenient for users by the end of the further study.

Tab. 5. Performance criteria and related measures

ABBREVIATION	MEASURE	EXPLANATION	FORMULA
R^2_{adj}	Multiple Coefficient of Determination	Percentage of variation in response explained by the model	$R^2_{adj} := 1 - \left(\frac{\sum_{k=1}^{N} (y_k - \hat{y}_k)^2}{\sum_{k=1}^{N} (y_k - \bar{y}_k)^2} \right) \times \left(\frac{N-1}{N-p-1} \right)$
AAE	Average Absolute Error	The average magnitude of errors	$AAE := \frac{1}{N} \sum_{j=1}^{N} \lvert y_j - \hat{y}_j \rvert$
RMSE	Root Mean Square Error	The square root of the mean squared error	$RMSE := \sqrt{\frac{1}{n} \sum_{j=1}^{n} (y_j - \hat{y}_j)^2}$
r	Correlation coefficient	The linear relation between the observed and predicted response	$r := \frac{\sum_{j=1}^{n} (y - \bar{y})(\hat{y} - \bar{\hat{y}})}{\frac{(n-1)}{\sqrt{s(y)^2 s(\bar{y})^2}}}$

Tab. 6. Accuracy performance criteria of MARS and CMARS models

	CMARS		MARS	
	TRAIN	TEST	TRAIN	TEST
R^2_{adj}	0.573	0.389	0.566	0.398
AAE	15.02	18.26	15.309	18.537
RMSE	25.4	35.87	25.742	36.071
r	0.764	0.655	0.757	0.650

Tab. 7. Accuracy performance criteria of MARS and CMARS models

	CMARS	MARS
R^2_{adj}	0.68	0.704
AAE	0.823	0.826
RMSE	0.708	0.714
r	0.857	0.858

Notes y_j*: jth* actual response value; $\hat{y}_j$*: jth* predicted (fitted) response value; $\bar{y}$: mean of the actual values; $\bar{\hat{y}}$: predicted response variable; $\bar{\hat{y}}$: mean of the predicted response variable; $s(y)^2$: standard deviation of the actual response variable; $s(\hat{y})^2$: standard deviation of the predicted response variable, n: number of observations; p: number of terms in the model. In any model, smaller values of for AAE and RMSE, close to 0, give better results, whereas for R^2_{adj} and r values closer to 1 are preferred.

The purpose is to achieve a potential predictive model by using the training dataset; the test dataset is also implied to measure the performance of the model (Hyndman & Koehler, 2006). For the intended and sought prediction of the general skills *(G),* the *MARS* and *CMARS* models, identified in the previous sections, were evaluated by applying the performance criteria formalised according to Table 6. That table reflects the matrices of performances in the training case and the testing case of the *MARS* and *CMARS* models obtained for the assessment or forecast of general skills *(G)*. Throughout this investigation, the authors prefer a rigorous approach from mathematics and statistics towards performance criteria or measures which is applied to the models. Hence, the scientific toolbox contains a truly operational, OR and optimisation-supported way to assess and quantify the uncertainty. The latter is given in the data and becomes translated into the models attained and rigorously compared by the authors. What is more, this study paid particular attention to the model aims and purposes of "accuracy" and "stability". In diverse and overall rich ways, these goals enter into our performance or comparison criteria and measures.

The values listed in Table 7 are compared with the stability performance for each comparison criterion on both train and test datasets. When the values are closer to one, they indicate a more stable model. Stable methods perform equally well on both training and test datasets.

4. Discussion of the results

The problem of competences in the context of the labour market is often addressed in the literature; however, not very often on a big sample of several thousand competence profiles and with statistical methods, including data mining such as *MARS* or *CMARS*. This pioneering research analysis presents a general skills G model for a group of students learning to be IT technicians in the Wielkopolska province. *MARS* and *CMARS* models were developed based on 2 173 competence profiles indicating 3 874 skills and 619 job offers, in which 3 133 skills were selected. The results were analysed for the influence of the dependent variables collected between 2012 and 2015 in the IT tool www.system.zawodowcy.org.

Human intelligence is an outcome of optimising the balance between robustification (stability), which can also be called routinisation, standardisation and others, and attentiveness to the important details in the observations. It is a standard for optimising the balance between socialisation and individualisation. Consequently, the article focused on two modelling approaches that set up a frame and delivered the response data: a general model and a reduced or simplified model. This step may be called the "forward problem". This helps to simplify large numbers of data (mostly connected with thousands of numbers of various skills) to use them for *MARS* and *CMARS* statistical analysis. The pre-processing model (simplified model), understood as a forward problem in this paper, was developed and implemented on a research sample during the analyses. The core part of the study consisted of the modelling work — the "inverse problem" — which gave the estimation results: *MARS* and *CMARS* models. During the analysis, the group of

general skills (y_G) was chosen as the independent variable. After 1000s of variables in the form of diverse skills describing competence models of the candidates and the demand for competences among employers were reduced with the simplified model, 15 variables were selected. They included the aggregated group of skills *G, C* and *P*, gender, age of the candidate, date of creation of the candidate profile, offer, offer visibility time, type of work (shift-based, permanent, etc.), shifts, the proximity of the job offer to the candidate.

The strengths of the article are the research methods used, the exceptionally large amount of data on the supply and demand of competencies, and the fact that the data is up-to-date and detailed, allowing the analysis in many occupational areas. This undoubtedly fills the research gap that allows many areas of competence, rather than being limited to selected professions and small group sizes (Stimac & Tanasic, 2023). The inference that was carried out in the article allows the method to be applied systemically and to refer to a large scale. Valuable studies of competency gaps proposed in the literature are sometimes subject to the error of objectivity, referring, for example, to a group of experts (Muzam, 2023). Another value of the conducted research and the developed research model is the possibility of ongoing monitoring of the level of competencies in the educational market before graduates appear in the labour market. The method developed is preventive in nature, characterised by higher efficiency than corrective actions occurring at the stage of professional work (Heimler et al., 2012; Alonso-Garca et al., 2020; Jędrzejczyk 2013).

In this study on the inverse problem, a mathematical and statistical approach was pursued towards performance and comparison criteria, which were applied to the models. This approach is viewed as closely connected with the real-world application, featuring human factors and interpreted accordingly. Within that approach, operational research was presented to represent, quantify and model uncertainty coming from a real-life context. This was described in terms of the given and pre-processed data and further explained, evaluated and discussed by the models. Herewith, a rigorous and meaningful comparison and assessment of the models was made. The models were designed and compiled based on *MARS* and *CMARS*, respectively. This work paid more attention to the modelling goals of "accuracy" and "stability" and to their trade-offs.

Given the developed *MARS* and *CMARS* models, it can be concluded that the demand for general skills *G:*

- is not affected by factors such as gender, age, date of creation of the profile in www.system.zawodowcy.org, date of creation of the offer in the system, type of employment, working hours, number of job positions for the published offer, stationarity of the work, and proximity of work;
- the model is affected by dependent variables such as time of visibility of the offer (from-to), work commencement time, whether the job is shift-based, and accelerated index for skill groups C and P.

Conclusions

The research conclusions include the fact that the duration of visibility and publication of the offer might be informative for job candidates and thus be of significant influence on the development of competences in the region. Another group of significant variables includes an accelerated indicator for skill groups common for given professions and professional skills. The studies confirmed the significant dependence of all skill groups on the demand for competences among employers. Stationarity and proximity of work do not matter since competence shortages are then covered by other candidates who know the employer's expectations or develop competences in the nearby schools.

Further works connected with data and competence models on the labour market concern applying *MARS* and *CMARS*, and further data mining methods: RMARS (Robust *MARS*) (Özmen & Weber, 2014), *RCMARS* (Özmen et al., 2011), *GPLMs, CGPLMs* and *RCGPLMs* (Hastie et al., 2009; Özmen et al., 2013), to represent and understand P, S and *G,* comparing all models and systems by statistical performance criteria, error diagrams, and sensitivity analyses.

The important parts of future research studies are the representation of our challenges from human resource management and intelligent networking in terms of Artificial Intelligence. This is a pioneering contribution by new powerful methods from mathematics, statistics, natural sciences, and neutral computing, carefully evaluated for the problems studied. It is worth pointing out that the time factor is used very rarely in mathematical models. In the developed

model, the time of the model is an independent variable as seasons may influence the number of job offers and the need for competences in the labour market. Time is thus important in the model. For the sake of brevity of the paper, the authors could neither work out the further rich details and facets of the approach nor state all of its interpretations and opportunities.

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University Social Responsibility in Poland: The Review of Codes of Ethics, USR Strategies, and Reports

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ABSTRACT

This study explores university social responsibility codes, strategies, and reports by higher education institutions that show their role in building socially responsible organisations to integrate a sustainability paradigm into research, teaching, and governance. The paper applies the content analysis method that systematically examines and interprets data to extract meaningful insights and understand patterns. The authors reviewed the codes of ethics, strategies, and social responsibility reports of 160 universities that have joined the Polish Declaration of University Social Responsibility. The research effort shows that sustainable development is a common aim among Polish higher education institutions. However, codes of ethics, social responsibility strategies, and sustainable development and social responsibility reports are not widespread practices among them. Polish higher education institutions are only beginning to professionalise their approach to social responsibility. This qualitative analysis only examined 160 Polish universities that have joined the Declaration of University Social Responsibility (USR). Because the selection of the sample is subjective, it is essential to cautiously assess the generalisability of the findings of this study. The article organises and systematises knowledge about the USR concept, which currently plays an important role in higher education institutions. Higher education institutions, such as universities, formulate strategies and codes of ethics and undertake initiatives to support sustainable development (SD). These results provide new insights into the possibilities of developing these documents. In practical terms, this study offers suggestions to higher educational institutions on improving their USR strategies, reports, and ethical codes, primarily focusing on adopting an approach centred around sustainable development goals.

KEY WORDS

university social responsibility (USR), university social responsibility declaration (USRD), codes of ethics, USR strategies, sustainability, USR reports, higher education institution (HEI)

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Introduction

Modern higher education institutions (HEI) compete to attract top scholars, administrative staff, international partners, projects, and donors. They also seek to secure top positions in university rankings. At the same time, the HEI mission is evolving from academic models towards that of "enterprise university" (Compagnucci & Spigarelli, 2020) to meet the expectations and demands of stakeholders and to gain an edge in international competition (Khovrak, 2020). This process cannot go without relying upon the concept of university social responsibility (USR),

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which impacts stakeholders, helps gain a good reputation, and improves the competitive positioning of a university as a brand (Azizi & Sassen, 2023). URS is a strategic and systemic approach to university administration. It is conducive to forging cooperation and dialogue with stakeholders. It fosters sustainable development, civic society values and attitudes, academic values, and new idea development; it helps maintain the continuity of research and develop research and teaching competence sets that are pivotal for effective operation and innovation (Kulczycka & Pędziwiatr, 2019). USR is regarded as an ethical and integral administration model that benefits universities and societies (Moghadam et al., 2021). The integral elements of a university's social responsibility are USR strategies, ethical codes, and reports.

Considering the above, this paper explores university social responsibility codes, strategies, and reports developed by higher education institutions. It highlights their role in building socially responsible organisations and integrating a sustainability paradigm into research, teaching, and governance. Moreover, it attempts to answer the following research questions:

- What is the role of USR in the management of higher education institutions?
- What role do USR strategies, ethical codes, and reports play in building socially responsible universities?

A description of the main findings from the literature review relevant to the purpose of this article follows the first part of the article. The next sections describe the research methods and the analysis results of USR codes of ethics, USR strategies, and USR reports conducted by HEIs that have signed the USR Declaration (USRD). Finally, the results are discussed, and the final conclusions are given.

1. Literature review

The USR concept reveals the social impact of HEIs in terms of education and research and highlights their capacity to trigger sustainable social, humanistic, and environmental changes (Hernández et al., 2022). Therefore, HEIs are responsible before the public not only for the quality of academic training and the generation of new knowledge (François, 2007) but also for the quality impact on social groups, developing a healthy environment and improving quality of life, work, and learning for its stakeholders (Hernández de Velazco, 2020). Consequently, universities impact the generation of competent and conscious human and social capital and relevant environmental capital (Vallaeys & Rodríguez, 2019). This responsibility towards society entails personal training for society's sustainable development and addressing major social issues, among them the climate crisis, global inequalities, environmental degradation, securing peace, etc. The new generations must see themselves as citizens of their own town or village, region, country, and the world (Ginkel, 2002). In addition, Spanish researchers have proven the existence of a close connection between academic training, empathy, values, and socially responsible behaviour of students (Tobón et al., 2014). These results can have direct implications on pedagogical practices and educational policies, given the importance of higher education based not only on academic and scientific training but also on values, ethics, and social responsibility. However, a focus on the meanings of USR or on identifying benchmarks leads to the potential impact of student involvement in USR projects being understudied (Coelho & Menezes, 2021). At the same time, teachers do not fully perceive the actions of the university's social responsibility and the role of social topics in their subjects; therefore, they do not sufficiently involve their students in these issues within their subjects (Abrahão et al., 2024). This requires updating the teaching curricula; besides, the importance of teamwork and cooperation must be reaffirmed; new strategies for university development must be put in place next to more effective tools for sustainable development. This leads to a heightened understanding that USR should be integrated with university strategy and operational practices (Lo et al., 2017).

Research to date demonstrates that the integration of social responsibility programmes into the educational process generates significantly better learning outcomes as students begin to acknowledge USR, learn how to handle complex and puzzling problems, develop the ability to apply professional knowledge in practice for the benefit of local business and region, master team building and communication skills (Ting et al., 2021). This is because university students are considered citizens responsible for future civil society. Therefore, HEIs are expected to help students understand democratic principles, norms, and ethics necessary for the sustainable development of modern society, in addition to providing them with quality professional knowledge.

It is also imperative for HEIs to incorporate social responsibility initiatives into their administrative

work and management procedures to achieve a meaningful impact through stakeholder involvement in the process of meaningful transformation of social issues (Ali et al., 2021). The integration of social responsibility aspects into university administration systems rests on selected international initiatives, among them, the United Nations Global Compact, PRME (Principles for Responsible Management Education), GRI (Global Reporting Initiative), or STARS (Sustainability, Tracking, Assessment and Rating System). These initiatives underlie the university's socially responsible action. It enhances the quality of management and helps sustain a competitive edge. Research suggests a strong and positive effect of USR on brand reputation, equity, and loyalty in public and private universities (Tan et al., 2022).

HEIs are increasingly considered key actors/creators of positive social change. Therefore, changing the approach to university administration also requires their development strategies and codes of ethics to be reviewed and updated; on top of that, new approaches to reporting should be followed. Such documents form a framework for stakeholder activities concerning HEI initiatives driven by social responsibility. Understanding stakeholders' expectations regarding the social responsibility of HEIs is fundamental to creating and implementing successful strategies and programmes (Santos et al., 2020). At the same time, competition in the marketplace also affects USR strategies, as HEIs adopt best market practices for sustainable development. As universities continue to work towards making the world a better place by fulfilling the so-called Third Mission of the University (Kola & Leja, 2015), the evolution of USR is likely to remain dynamic, as HEI are bound to continue to make constant efforts to meet global challenges and contribute significantly to sustainable development.

Many universities are addressing sustainability issues by, on the one hand, creating academic programmes, establishing research centres, and undertaking other research and educational initiatives, and, on the other hand, reporting socially responsible activities (Dagilienė & Mykolaitienė, 2015). Universities prepare sustainability reports as the primary institutional documents to evaluate and communicate their initiatives aimed at achieving sustainable development. In turn, monitoring and reporting on USR contributes to strengthening social values and making all stakeholders understand their responsibility. However, universities may be disinclined to report due to excessive standards governing non-financial disclosures. Preparing reports requires significant costs and time (Sassen et al., 2022). The institutionalisation of the concept of USR requires formal institutions to be put in place that would ensure sustainable (legal, organisational, and common) conditions for repetitive human behaviours and people-to-people interactions (Spychalski, 2008). Among the most critical institutions of this kind are the code of ethics, which underpins social responsibility, USR strategy, and USR report. Research on the institutionalisation of USR, including analyses of key documents, is not abundant. For example, a content analysis technique to a selected sample of 20 strategic plans issued by large and mega Italian universities showed that to date, Italian public universities still pay little attention in their planning documents to objectives regarding the multiple dimensions of Social Responsibility, mainly in relation to environmental issues, a failure detrimental to University Social Responsibility implementation and achievement (Nardo et al., 2021). In turn, Amiano Bonatxea et al. (2022) analysed a few available reports of the European HEI prepared according to the latest version of GRI standards and discovered that the GRI general issues, common to all types of organisations, are adequately reported by HEIs, but difficulties are encountered in integrating a vision that incorporates the role of their missions in standards related to economic, social and environmental aspects. By contrast, Alcántara et al. (2022) carried out an exploratory study in search engines, directories and university websites, analysing typology, stakeholders or the organisational structure managing USR and showing how USR reports were communicated and published. A study conducted by Pactwa et al. (2024) was based on the content of open information published on the university's website of selected Polish and European HEIs. It indicated that according to the current strategic plans of Polish HEIs, the process of integrating USR into strategic plans is visible at 61.6 % and 43.8 % of strategic plans refer to SDGs, unlike foreign universities with 37.2 % and 62.8 %.

This research aims to explore USR codes, strategies, and reports drawn up by HEIs using content analysis methodology.

2. Materials and methods

The analysis of codes of ethics, USR strategies, and USR reports done by HEI, which had signed the USR Declaration (USRD), was performed in April 2023 and employed the content analysis method.

Until April 2023, 160 Polish HEIs had joined the USRD (gov.pl, 2023).

The research process consisted of the following stages:

1. Selection of the sample: The study focused on all 160 Polish HEIs that had signed the USRD by April 2023.
2. Data collection techniques:

- Primary data collection: researchers utilised search engines embedded in the official websites of the examined HEIs to locate relevant documents (codes of ethics, USR strategies, and USR reports);
- Supplementary data collection: When internal search engines returned no results or provided limited information, the Google search engine was employed with keywords such as "code of ethics", "USR strategy", and "sustainability report";
- Verification of data: collected documents were cross-checked to ensure their validity and representativeness.

3. Document categorisation: The collected materials were grouped into three categories: codes of ethics, USR strategies, and USR reports. They were then further classified based on content, structure, year of publication, and stakeholders addressed.
4. Content analysis: both quantitative and qualitative approaches were applied:

- Quantitative analysis: Statistical data on the presence of documents, their length, and frequency of stakeholder references were recorded.
- Qualitative analysis: The content of the documents was examined to identify recurring themes, such as alignment with the UN Sustainable Development Goals (SDGs) or stakeholder engagement.

Of the 160 signatories of the USRD, 56 HEIs (35 % of the total number) possessed a code of ethics. A similar number of HEIs (43) had adopted a code of student and/or PhD student. Instead of laying down their own code of ethics, 12 HEIs had decided to formally adopt or refer their staff members to the Code of Ethics for Research Workers adopted by the Polish Academy of Sciences (PAN) and/or the Code of Best Practice in Higher Education Establishments endorsed by the Conference of Rectors of Academic Schools in Poland (CRASP). Five universities adopted two separate codes intended for different staff groups: one for teachers and one for administrative staff. The codes of 54 USRD signatories were analysed (33.75 % of the total), while access to these documents was limited in the case of two HEIs. In total, 56 codes were reviewed (two of the examined HEIs had drawn up two documents each for different employee groups).

Of the 160 USRD signatories, only seven (4.37 % of the total) provide information about USR strategies on their official websites. One of them, however, had only published the rector's decision on introducing USR; another one was only sharing a brief note about USR instead of a full strategy (it highlighted four strategic areas and four most relevant focus areas of the university); in yet another case, information on the sustainable development of the university (within its 2010-2040 strategy) only referred cursorily to selected action areas. Finally, the analysis covered the content of the strategies adopted by four USRD signatories (2.5 % of the total): Kozminski University, WSB University, SGH Warsaw School of Economics, and Warsaw Medical University.

Of the 160 signatories of the USRD, only 25 (15.6 %) had published USR reports on their official websites. Only 18 of the examined organisations (11.3 % of the total) had prepared the reports in separate documents containing information on social responsibility and sustainability. The remaining seven reports out of 25 only outlined some activities and projects and shared some information under one of the university website tabs. Ultimately, the reports of 18 USRD signatories (11.25 % of the total) were examined in detail. The reviewed documents (codes, strategies, and reports) were compared in terms of the year of publication, title, stakeholders (the direct recipients of the documents and the general public), length, and structure.

3. Research results

3.1. Year of publication

A closer look at the years the USRD signatories adopted their respective codes does not suggest an increasing interest in these documents. However, two years seem to stand out: 2011 and 2021. As regards the latter date, apparently, the growing interest in the HR Excellence in Research Award granted by the European Commission was likely to have a substantial impact. Yet the rationale behind the adoption of the relatively high number of codes in 2011 is not easy to pinpoint. Notably, the first two codes were adopted at Polish universities as early as 2003. The

trailblazers were the Stanisław Staszic Academy of Mining and Metallurgy (AGH University) in Kraków and the Jagiellonian University in Kraków.

Speaking of strategies, only one fails to provide the date of adoption; one was adopted in 2021 and two in 2022.

All the analysed USR reports apply to a specific reporting period or the year of publication. Work on the USR reports began in 2017. The longest reporting period was six years, covering 2017-2022 (one case). The other reporting periods are 2017-2018 (one case), 2018-2021 (two cases), 2019-2020 (two cases), and 2021 (three cases). However, most reports concerned the reporting period of 2021-2022 (nine cases). In most cases, the reviewed documents were a follow-up to the signature of the USRD by the relevant university and the reporting requirement contained therein. The authors of several reports admit that this was their first publication of this type, but it is planned to be further developed and improved. It is worth noting HEIs for which USR reporting is nothing new. The AGH University in Kraków has already drawn up two reports on socially responsible activities (one was published in 2017 in response to the initiative of the United Nations Global Compact; the other came out in 2020 and covered 2019-2020). Similarly, two reports on the USRD monitoring were prepared by Powiślański University in Kwidzyn (the reporting periods were 2019-2020 and 2020-2021).

3.2. Title

Most of the reviewed codes were titled "codes of ethics" (45 cases - 80.35 %), less often "ethical codes" (five cases) or "codes of values" (two cases). Some of the documents also named their recipients. The most popular were university teachers (15 cases), less often all university personnel (11 cases), or non-academic staff (six cases). In some cases, the code was named "rules of ethics/ethical principles" (three cases, Fig. 1).

More than 30 % (nine out of 25 reports) of the studied reports prepared by HEIs are called "USRD implementation reports". Such reports are drawn up based on a self-assessment form designed by the USR Working Group operating within the ministry's Team for Sustainable Development and Corporate Social Responsibility. Another set of documents was "USR reports" (28 %). The Wrocław University of Economics had prepared a broad and comprehensive report, University's Sustainable Development Goals. The Adam Mickiewicz University in Poznań had followed a similar line of thought and had penned a document called Engaged University 2022.

3.3. Stakeholders

In most cases, the entire academic community, i.e., teachers, office staff, and students (19 documents - 33.9 %), must comply with the codes adopted by the USRD signatories. The second most popular group of addressees is university teachers (16 cases). 14 HEIs have a code embracing all employees; six follow a code intended for anyone but academic staff. To highlight who the actual recipients are, some HEIs point directly to academic staff (25 cases - 44.64 %); in four documents they are referred to as "academic researchers" or "scholars"; four others name them "research and teaching staff". Other codes adopted by the USRD signatories speak directly to students (14 cases - 25 %) and administrative staff (also 14 cases), also referred to as "non-academic staff" in ten of the analysed codes. Fig. 1 lists stakeholders bound by the codes formulated by the USRD signatories. It is also worth noting three HEIs that offer programmes in the arts as they use inclusive language in their codes by referring to "persons who study" and "persons who work", thus avoiding a gender-biased term (The Code of Ethics of the Community of the Jan Matejko Academy of Fine Arts in Kraków, The Code of Ethics of the Academy of Fine Arts in Gdańsk, and The Code of Ethics of the Leon Schiller National Higher School of Film, Television and Theatre in Łódź). Moreover, two of these HEIs emphasise that the code applies to all personnel regardless of the type of employment contract (part-time, full-time, etc.).

In their codes, the USRD signatories declare to assume specific obligations towards stakeholders. In most cases, they assume the responsibility towards students (29 cases - 51.8 %) and PhD candidates (12 cases), less often towards other members of the academic community (8 cases, Fig. 2).

The strategies of the USRD signatories recognise responsibility towards employees (two cases - 50 % of the respondents), students (two cases), candidates (two cases), the ministry in charge of science and higher education (two cases), NGOs (two cases), local community (two cases), and society (two cases). Two different approaches to identifying key stakeholders can be discerned: they are seen either as a general category or as specific entities (Table 1).

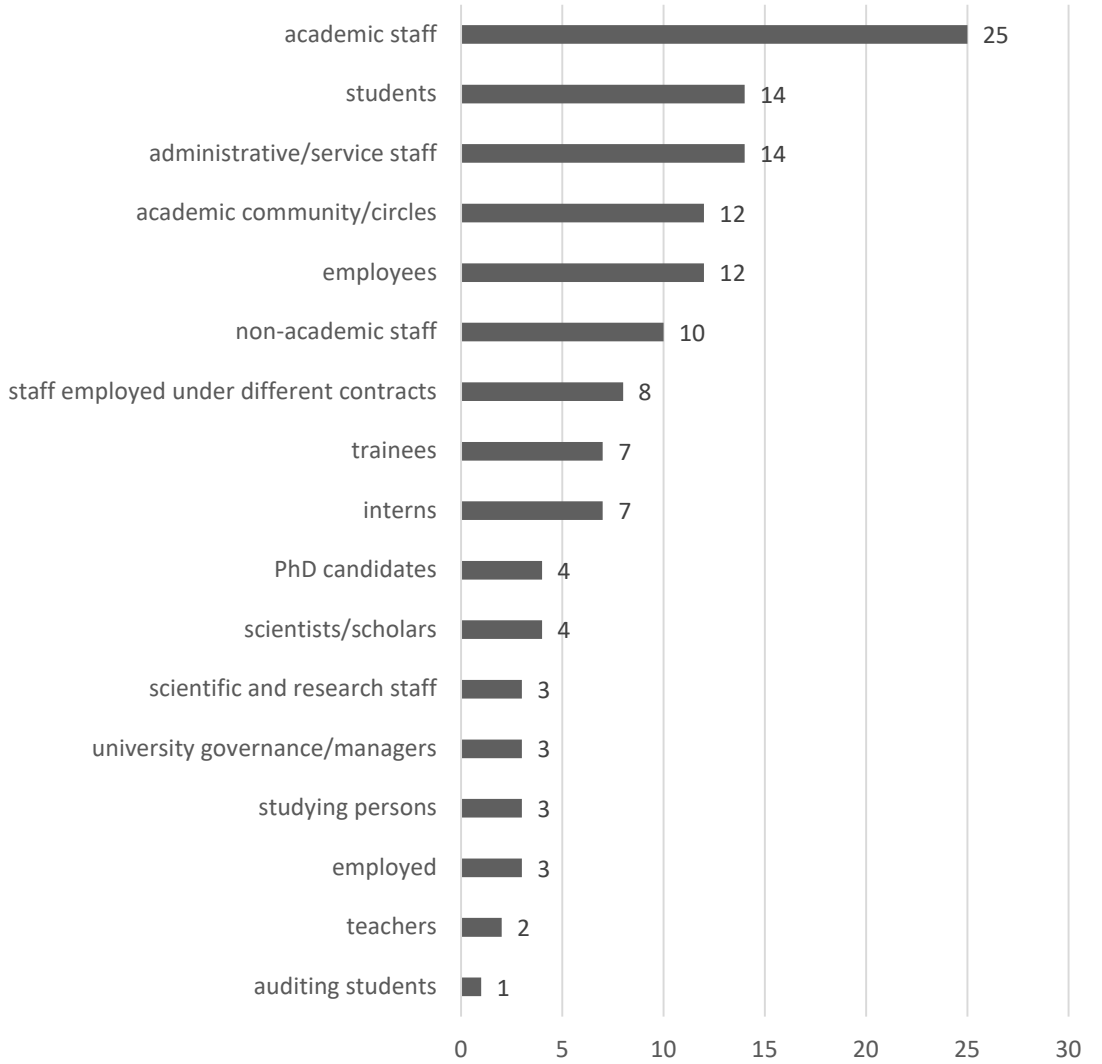

Fig. 1. Stakeholder groups obliged to follow the codes adopted by the USRD signatories

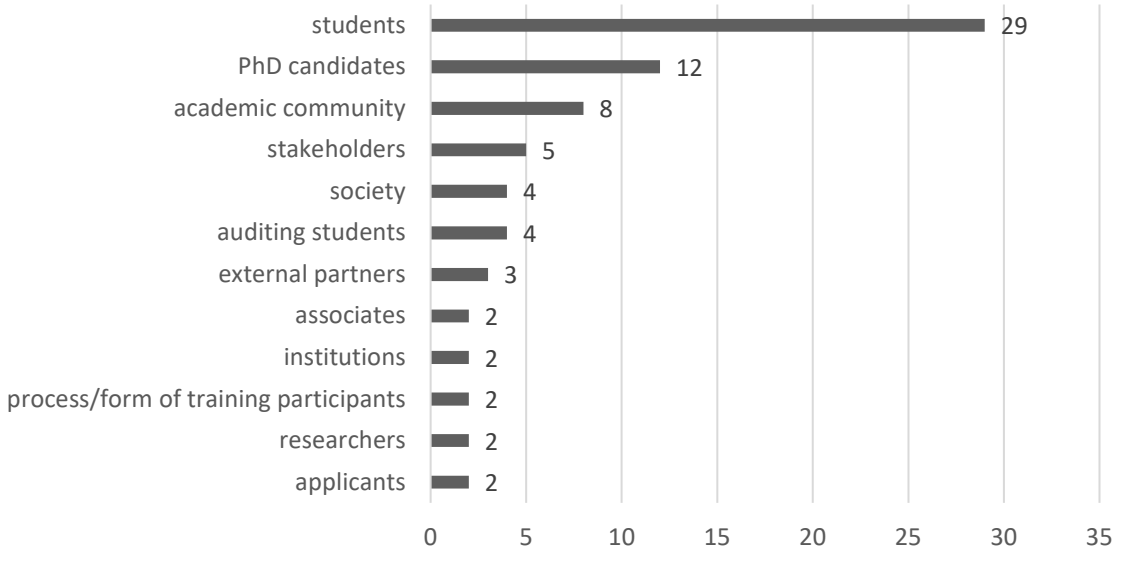

Fig. 2. Stakeholder groups towards which the USRD signatories declare to assume responsibility

Tab. 1. Stakeholders identified in two selected strategies of the USRD signatories

Warsaw School of Economics (SGH)	Warsaw Medical University (WUM)
Joint stakeholder groups	
Employees	
Students	
Candidates	
Ministry for science and higher education	
Non-governmental organisations	
Local community	
Society	
Various stakeholder groups	
PhD students	Research partners of WUM
Auditing students	Ministry of Health
Suppliers	Medical Research Agency
SGH Partners' Club	Office for Registration of Medicinal Products, Medical Devices and Biocidal Products
Other regulators	Agency for Health Technology Assessment and Tariff System
Trade unions	State Sanitary Inspectorate
Accreditation and control bodies	State Pharmaceutical Inspection
Mass-media	e-Health Centre
Partner universities	National Health Fund
HEIs	National Institute of Public Health — National Institute of Hygiene
Graduates	National Medicines Institute
Enterprises	National Centre for Research and Development
Elementary and high school students and teachers	Polish National Agency for Academic Exchange
Central and local government administration	Institutes of the Third Age
	Pharmaceutical industry
	Local government units

3.4. Length of documents

The codes are generally concise documents. Except for three documents, their size ranges from one to eight pages. The most popular length is four pages (15 cases - 26.8 % of the reviewed documents), followed by six (seven HEIs) and two (seven HEIs). The Code of Employee Ethics and Conduct of the SGH Warsaw School of Economics is the longest. It has 32 pages. It is, in fact, a stand-alone volume with a high-quality layout and graphics, which can partly explain its size. The Code of Ethics of the University of Economics in Katowice is also relatively long (18 pages), just like the Code of Ethics of the Academic Staff of the University of Gdańsk (13 pages).

The size of the four examined strategies ranged from 9 to 20 pages. More details are provided in Table 2, which also offers a careful comparison of the documents.

The length of USR reports varies from several to several dozen pages. However, in two cases, it is more than 100 pages. None of the reviewed reports has less than ten pages. Most often, the length of reports ranges from 14 to 19 pages (seven cases - 38.9 %) or from 40 to 60 pages (four cases). Less frequently, the reports number 80 pages or more (three cases). The Social Responsibility Report of the University of Economics in Kraków is by far the most extensive lengthwise (107 pages). Also, the Engaged University 2022 report is comparatively long. It was drawn up by the personnel of the Adam Mickiewicz University in Poznań and has 91 pages.

3.5. Structure of documents

The structure of the reviewed documents varies. The codes of six HEIs contain a mission statement (the University of Entrepreneurship and Administra-

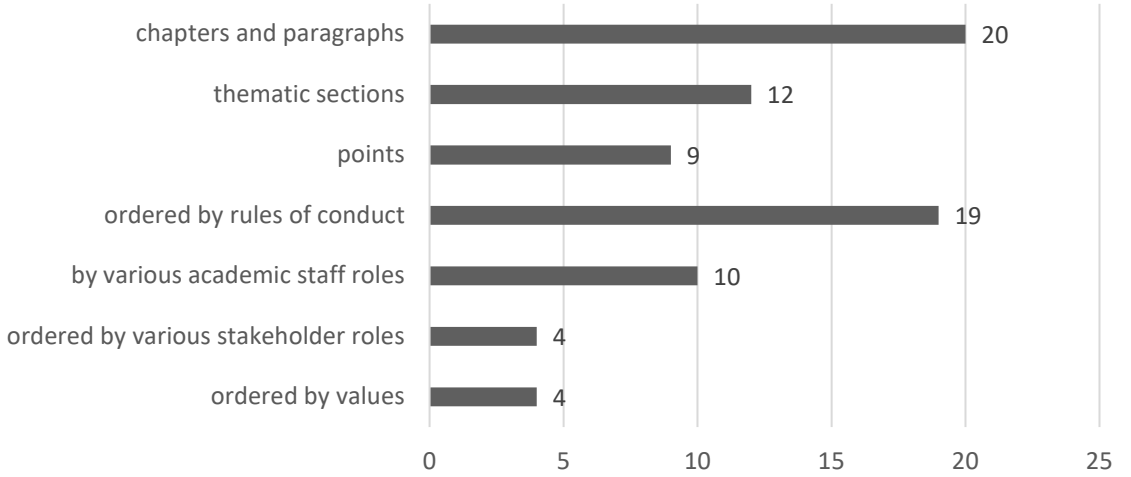

Fig. 3. Structural components of the codes adopted by the USRD signatories

Tab. 2. Comparison of the main items of the USR strategies of the USRD signatories

Part of USR strategy	Name of university			
	Kozminski University	WSB University	Warsaw School of Economics (SGH)	Warsaw Medical University (WUM)
Full strategy name	Sustainability Transition Strategy of Kozminski University	Sustainable Development Strategy 2030 — WSB University	Strategy of Social Responsibility of the SGH Warsaw School of Economics	Strategy of Social Responsibility of the Medical University of Warsaw
Strategy size (in pages)	9	11	20	19
English version	-	-	+	-
Rector's foreword	+	+	+	+
Persons responsible for strategy development and implementation	+	+	-	-
Mission, vision, values, and motto	-	-	+	-
Stakeholders	-	-	+	+
Stakeholder matrix	-	-	+	-
Strategic objectives linked to the United Nations Sustainable Development Goals	+	+	+	+
The United Nations Sustainable Development Goals	Goal 4, 5, 9, 11, 12, 17	Goal 4, 5, 8, 9, 11, 12, 17	Goal 4, 7, 8, 10, 12, 17	Goal 3, 4, 5, 6, 10
Number of operational objectives	-	-	13	7
Number of indicators	-	-	23	4

tion in Lublin also shares the vision of the university). Only one code opens with the rector's foreword (The Code of Employee Ethics and Conduct of the SGH Warsaw School of Economics). The codes are mostly structured into chapters and paragraphs (20 documents - 35.7 % of the analysed documents), less often split into thematic sections (12) or simple clauses/points (nine). The bodies of the majority of the codes are built around specific rules of conduct (19 cases - 33.9 %) or the different roles of academic staff, e.g., employee, researcher, instructor, participant of public life (ten cases); less often, they follow a description of values (four) or stakeholders, e.g., students, PhD candidates, university authorities, or administration (four cases, Fig. 3). Only one code contains a chapter on the relations of the university with external partners (The Ethical Principles of the Academic Community of the Witelon State Higher Vocational School in Legnica). When examining the sole structure of certain codes, it becomes evident that the authors

Tab. 3. Achievement indicators for the USR strategies adopted by the USRD signatories

Warsaw School of Economics (SGH)	Warsaw Medical University (WUM)
Quantitative indicators	
1. Number of studies and publications which refer to surveying stakeholders' expectations	1. Number of completed and reported educational initiatives intended both for students and staff and for local community and general public
2. Share of research and publications on social and environmental issues in all staff's research and literary output	
3. Number of projects addressing social responsibility and sustainable development carried out by the university	
4. Number of open-access research publications of SGH staff (including the number of publications in the SGH Open Digital Repository)	
5. Number of students contributing to bodies responsible for university programme design	
6. Number of majors and teaching projects that cover issues related to ethics, sustainability, and social responsibility	
7. Percentage of teaching and administrative staff trained in addressing non-standard students, PhD candidates, and auditing students' special needs	
8. Number and nature of initiatives aimed to support persons with special needs	
9. Number of initiatives (and the number of their participants) intended for attendees other than students and post-graduate students divided by form and participant group	
10. Percentage of stakeholders partaking in dialogue (by form and stakeholder group)	2. More individuals obtaining extra qualifications and gaining new knowledge from educational programmes implemented by WUM
11. Percentage of stakeholders involved in participation (by form and stakeholder group)	
12. Number and type of solutions adopted to facilitate cooperation with SGH (by form and stakeholder group)	
13. Number and type of solutions introduced to broaden the university offer and availability	3. Significant reduction in water consumption
14. Percentage of employees partaking in dialogue (by form and employee group)	
15. Percentage of employees participating and volunteering (by form and employee group).	4. Reduced water consumption bills (including individual)
16. Average number of training days per employee (by employee group and identifying the type of initiative: development/training, paid/unpaid by the university)	
17. Number and type of implemented administrative solutions facilitating work-life balance; percentage of employees covered (by form and employee group)	
18. Number of reported cases of discrimination and mobbing and information on preventive and corrective action	
19. Utilities consumption figures (water, electricity, and heat) per user/employee	
20. Volume of generated waste and pollutant emissions generated per year per user (by category of refuse — mixed, segregated, and bio)	
21. Number of initiatives in the area of environmental education involving employees, students and PhD candidates; number/percentage of people who attended	
Qualitative indicators	
1. Satisfaction index for students, PhD candidates, auditing students	
2. Employees' level of satisfaction based on periodic satisfaction surveys	

(universities) sought inspiration from one another, at least in the case of eight documents. Some similarities in the wording can even be discerned.

The analysis of the main structural items of the USR strategies adopted by the USRD signatories reveals their intended concision. They open with the rector's message and a brief description of the university. The strategies devote much room to the description of the UN Sustainable Development Goals (SDGs) that are considered top priorities for HEIs. The most frequently named SDGs are Goal 4 Quality Education (four HEIs), Goal 5 Gender Equality, Goal 12 Responsible Consumption and Production, Goal 17 Partnerships for the Goals, Goal 8 Decent Work and Economic Growth, Goal 9 Industry, Innovation and Infrastructure, Goal 10 Reduced Inequalities, and Goal 11 Sustainable Cities and Communities (three HEIs). The structure of the USR strategies often simply contains items linking to the UN Sustainable Development Goals (three cases - 75 % of the analysed HEIs); less often, they are arranged in thematic chapters and paragraphs (one case). The main strategy items are put together and compared in Table 2.

As shown in Table 2, the USR strategy of only one university (SGH Warsaw School of Economics) contains the mission statement, vision, values, and motto. It provides for a monitoring system to oversee the implementation of the strategy. The monitoring system provides for the following requirements: drawing up reports on the university's social responsibility (at least once every two years); regular tracking of strategy-related actions (at least once a year); regular verification of the achievement of operational objectives and the level of achievement of indicators (at least once in two years) (SGH Strategy, 2021). The indicators adopted for monitoring the implementation of the USR strategy are listed in two USR documents. It transpires that the examined HEIs most frequently resort to quantitative (25) rather than qualitative (two) indicators (Table 3).

In terms of structure, the reviewed USR reports fall within two main sets: (i) reports on USRD implementation progress drawn up in line with the 12 USRD principles and the methodology designed by the USR Working Group appointed by the Team for Sustainable Development and Corporate Social Responsibility and (ii) USR reports prepared according to the HEI's methodology. When preparing the reports, the USRD signatories mainly relied on the university self-assessment form provided by the USR Working Group. In the form, each USRD principle was accompanied by general guidelines as to which information was necessary and expected to be included in the report.

The review showed that most reports in this group differed in terms of the level of detail of the presented information and data, graphic design, or presentation of content in a tabular form. Some reports merely provide a concise description of activities falling within the scope of the USRD principles (social responsibility reports of the Łódź University of Technology, the Academy of Applied Sciences in Tarnów, or the State Higher Vocational School in Ciechanów). The report produced by the Jan Długosz University of the Humanities and Natural Sciences in Częstochowa shares its USR initiatives in a tabular form. In contrast, the Social Responsibility Report of Kozminski University in Warsaw contains a wealth of graphic forms in addition to comprehensive descriptions. Apropos, an attractive graphic design of the reports, especially those containing a large amount of information and numerical data, promises a positive reception from the reader.

In the case of the USR reports drawn up based on HEI's own methodology, certain fixed elements and reporting areas can be identified. Most of them share a foreword by the university governance (rector). Other topics and areas of interest covered in the reports on socially responsible activities are itemised in Table 4.

Interestingly, two of the USR reports differ slightly in their structure compared with others. One is the report of the Wrocław University of Economics entitled, University's Sustainable Development Goals. The report is available in two language versions: Polish and English. In addition to the regular introduction and a few opening remarks about the university, the report offers a comprehensive description of the entity's socially responsible initiatives, which are aligned with the 17 Sustainable Development Goals of the United Nations. The report highlights projects and activities that the staff and students of the Wrocław University of Economics undertook in the years 2017-2022. Another approach to USR reporting, although as holistic as at Wrocław, was adopted by the Adam Mickiewicz University in Poznań (UAM). The UAM report was entitled, Engaged University 2022. The title alludes to the university's Poland-first accreditation as an engaged university awarded by the Accreditation Council for Entrepreneurial and Engaged Universities (ACEEU). The report comprises the following structure items: Rector's message, UAM in numbers, UAM in rankings, accreditation, and aid to Ukraine. In addition, the

Tab. 4. Matters addressed in USR reports by the USRD signatories

USR report structure item	Areas covered in USR reports
Author(s)	Only a small number of reports (9 %) disclose their authors' names
Rector's foreword	Statement of the intention and nature of the report
Introduction	A brief description of the organisation and explanation of the reporting methodology Reference to SDGs
University stakeholders	Identification of internal and external stakeholders
Social action	Monitoring the social structure of the university Initiatives for the student community University response to the Covid-19 epidemic Cooperation with social organisations Initiatives for persons with disabilities
Research and teaching activities	Initiatives aimed at combining various disciplines in education (interdisciplinarity) Scientific and research centres Promotion of health
Economic initiatives and cooperation	Financing university operations, especially in USR Strengthening cooperation with external stakeholders regarding innovation
Environmental action	Best practice in environmental action Environment-oriented events (debates, conferences, festivals, etc.)
Initiatives promoting diversity	University Diversity Day Diversity card
Promotion and dissemination of science	Awards Educational projects for children Meetings with experts

Source: elaborated by the author.

document highlights four main categories of focus: People, City, Environment, and Kaleidoscope. Each contains initiatives around the social impact of the university on its milieu, the quality of cooperation with external partners, and the implementation of the idea of social responsibility, including SDGs.

4. Discussion of survey findings

Very few studies exist on the implementation of USR in universities in Poland. A pioneer in this area was Geryk, who, from 2007 to 2010, carried out a project in Poland entitled "Social responsibility of universities in the perception of stakeholders". The author conducted comprehensive studies, which proved that USR was understood by universities and their stakeholders practically exclusively as social involvement, i.e., activities for the benefit of society and the local community (this is how the author of the study presented this concept in the survey questionnaires). The researcher referred to the institutionalisation of USR only in one question of a representative quantitative survey of Tricity residents, asking whether pro-social activities should be published in the form of a report prepared by the university (34.4 % of respondents agreed with this) or in the form of an audit of such activities by an independent organisation (60.8 % of answers "yes"). The researcher asked the same question to 81 managers of Polish universities: 41.2 % of managers from public universities and 47.2 % from non-public universities agreed that activities for the benefit of society should be communicated in a report, and 50 % of managers from public universities and 47.2 % from non-public

universities agreed that such activities should be assessed by an external audit. 20 % of managers of public universities and 39 % of managers of non-public universities believed that universities should inform in some special way about their activities for the benefit of society (Geryk, 2010, 68, 97). The small number of universities that currently publish USR reports shows that the beliefs of managers have not evolved significantly since that period.

Subsequent Polish studies on USR are mainly fragmentary and focus on case studies. For example, research by Tenety-Skwiercz (2017, 317) in five of the most important Polish economic universities serves as a basis for stating that in June 2017, only one of them had an USR strategy, and two had an employee code of ethics. This research shows a similar result, i.e., universities with a USR code and strategy are still in the minority. Analyses conducted by other researchers show that the first university codes of ethics in Poland were adopted in 2003 by the Jagiellonian University, Wrocław University of Science and Technology, and the AGH University of Science and Technology in Kraków (Gałat, 2018). The first Polish USR strategy was the Social Responsibility Strategy of the Faculty of Computer Science and Communication of the University of Economics in Katowice in 2012 (Jastrzębska et al., 2019, 294). Until 2018, the only USR report in Poland was published by the Faculty of Computer Science and Communication of the University of Economics in Katowice (Dąbrowski et al., 2018).

In 2019, a comparative analysis of the experiences of Poland and Ukraine in the field of USR was conducted, which showed that universities in both countries recognise the importance of USR in creating a positive impact on regional development (Khovrak, 2020). A survey in which representatives of over 60 universities from Poland and Ukraine participated allowed for the identification of the main motives and barriers to implementing the USR concept. Additionally, the use of the case study method based on data from 40 Polish universities allowed for the development of a list of the most effective USR practices. The study showed that the implementation of the USR concept allows universities to actively participate in the life of the region and the country by identifying needs, engaging stakeholders, supporting cooperation, disseminating good practices and developing sustainable development strategies.

According to the report Diagnosis of the Implementation of Social Responsibility of Universities conducted in 2022 in 46 universities, 55 % of universities had a document of the implementation of the USR created by the top management for the entire university and a code of ethics — 35% (n=39), while a social report/USR/sustainable development was published by 23 % of the surveyed universities and another 62 % planned to do so within the next 2 years (n=35) (Lulewicz-Sas et al., 2023, 31, 35, 37). This study is the most comprehensive (after Geryk's study) and up-to-date diagnosis of the level of USR in Polish universities to date. However, it does not refer to the content of the above-mentioned documents.

Conclusions

As demonstrated in the analysis, codes of ethics are still relatively rare at HEIs (only 33 % of the USRD signatories have them in place). An improvement, however, is that most of the existing codes address the entire academic community and not only academic or non-academic staff (although many speak exclusively to them). Still, while identifying university responsibilities towards its immediate setting, the codes should pay more attention to the needs of various stakeholders. Certain key concepts also need clarification; for example, a clear dividing line should be drawn between values and rules of conduct. The review of the code contents shows that when drafting such documents, HEIs are inspired by the PAN or CRASP codes and their own output. In this context, however, huge emphasis should be placed on the codes' operationalisation. Their content does not seem to facilitate it, which becomes evident when studying the drafting process or being aware of the bodies responsible for putting them in place.

USR strategies are not common at universities (only 4.4 % of the USRD signatories have them). A closer look at the content of the strategies shows that when making these documents, HEIs are inspired only by the UN Sustainable Development Goals, and they fail to define specific operational objectives or indicators that help measure progress.

Also, sustainability/USR reporting at Polish HEIs is not yet common. It is in its infancy, which may testify that Polish HEIs have barely begun to professionalise their SR activities. They are making the first attempts to identify areas of responsibility, which are then communicated on official websites or published reports (Sady & Galat, 2022). The research conducted

for this paper demonstrates the limited extent of USR reporting. Of the 160 signatories of the USRD, only 16 % have published USR reports on their official websites to date. The reviewed USR reports differ significantly in structure, content, and length. Moreover, few Polish HEIs produce reports that offer specific indicators that measure the social and environmental impact of the university; if they did, it would help them communicate the effectiveness of their SR action. The quality of the published reports also leaves much to be desired. One reason for that is the lack of uniform and clear-cut reporting guidelines for individual sectors. Although the widely acknowledged global reporting initiatives (GRI) guide specific sectors (energy, finance), they have not yet developed similar practices for the HEI sector. Building socially responsible universities in Poland remains a major challenge and a key goal to pursue in the future.

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Exploring the determinants of university incubator performance in Morocco

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ABSTRACT
This study investigates the determinants of university incubator performance in Morocco. It aims to understand the factors influencing the effectiveness of these incubators and their contribution to economic development, addressing the gap in assessing their real impact despite their recent proliferation. This study employs a qualitative methodology based on a case study approach of six incubators. Data is collected through document analysis of scientific literature, public policies, and activity reports, accompanied by semi-structured interviews with incubator managers, university administrators, incubated entrepreneurs, and key ecosystem players. Thematic analysis is used to identify and explore the key determinants of incubator performance. The study reveals several critical factors affecting the performance of university incubators in Morocco. These include incubator characteristics, the external environment, and attributes of the incubated entrepreneurs. The findings provide insights into the elements that contribute to the success or failure of these incubators, underlining areas for improvement and optimisation. This paper contributes to the existing literature on university incubators by providing a nuanced understanding of the specific factors influencing their performance in a Moroccan context. It extends current theories by incorporating the interplay of internal and external factors and offering a detailed analysis of their impact on incubator effectiveness. This research offers valuable recommendations for policymakers, university administrators, and incubator managers. By identifying key performance determinants, the study informs the developers of targeted strategies to enhance incubator effectiveness and boost their role in fostering innovation and entrepreneurship in Morocco.

KEY WORDS
university incubator, determinants of performance, entrepreneurship

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Introduction

Entrepreneurship is often seen as a key driver of economic growth and job creation. Although the United States (US) was the first to initiate business incubation programmes and accelerators to foster development and stability, many other countries have since followed suit (Osiobe & Winingham, 2020). Today, business incubators are an integral part of business ecosystems in many countries and play a vital role in driving economic growth (Siddiqui et al., 2021).

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In this context, university incubators have emerged as principal players in fostering innovation and entrepreneurship within academic institutions (Etzkowitz, 2016). These specialised entities create an ideal environment for generating revenue while fostering mutually beneficial relationships among universities, business sponsors, government, and society, with a focus on financial, legal, and technical support (Hassan, 2020). However, despite the rapid rise of incubators, particularly in Morocco, their effectiveness and real impact have not been sufficiently evaluated (Fakhri et al., 2023). In addition, measuring business process performance is important for universities and businesses, as it helps connect incubator success factors with commercial strategies to ensure better performance (Gozali et al., 2020).

In Morocco, an emerging country undergoing rapid transformation, where innovation and entrepreneurship are gaining importance, understanding the determinants of university incubator performance is necessary to optimise their effectiveness. Although studies have outlined their potential, little research has focused on the specific factors influencing their performance in the Moroccan context, an area where practices and challenges may differ from those observed in other parts of the world (Fakhri et al., 2023). A number of questions remain unanswered: what are the key factors influencing the performance of these structures in Morocco? How do the characteristics of incubators, their external environment and the profiles of incubatees interact to determine their performance? This study aims to fill this gap by exploring the determinants of university incubator performance in Morocco and identifying the key elements that contribute to their success or failure.

To this end, a qualitative methodology (a case study of six incubators) is adopted based on document analysis and semi-structured interviews. Documentary analysis enables the exploration of the scientific literature on university incubators, public policies on innovation in Morocco, and the activity reports of the incubators studied. Semi-structured interviews with incubator and university managers, incubated entrepreneurs and key players in the entrepreneurial ecosystem provided rich, nuanced data on the perceptions and experiences of the various players. The data is then analysed using a thematic approach, enabling the identification of the main determinants of Moroccan university incubator performance.

The findings of this study have important implications for policymakers, university administrators, and incubator managers. By identifying the critical factors influencing incubator performance, this research can inform the development of targeted strategies to enhance their effectiveness and maximise their contribution to innovation and entrepreneurship in Morocco.

1. Literature review

1.1. University incubators

History reveals that the first university incubators were created in the United States when American universities became a breeding ground for entrepreneurial activity. Their birth followed the launch of innovation centres through an experimental research and development programme by The United States National Science Foundation in 1973 and its extension in 1981 (Osiobe & Winingham, 2020; Mian, 1997). Nevertheless, the definitions of these incubators vary from one author to another, reflecting the diversity of their missions and objectives.

Mian (1997), one of the first researchers to take an interest in university incubators, considers that university incubators aim to support the creation of incubated companies during the start-up years with value-added contributions such as rent reductions, access to capital, shared office space, university-related services like laboratories, technology transfer services and interim faculty consultants. Often, these are entities established by governments to foster entrepreneurial ecosystems by supporting the development and growth of spin-offs and small and medium enterprises (SMEs) (Muslim Saraireh, 2021). These two definitions, and many others (Hassan, 2020), focus on the support provided by university incubators for start-ups.

According to Adriansyah and Rimadias (2023), university incubators are created on the initiative of academic institutions or research centres to develop the knowledge economy based on scientific discoveries and technology transfer. These structures can take many forms: they can be located on or off campus, owned by a single university or several, be generalist or specialised, etc. Their appeal stems from the potential offered by the ability to link technology, capital and know-how. University incubators capitalise on entrepreneurial talent and help accelerate technology commercialisation by fostering new knowledge-based businesses (Kulkarni et al., 2024). Thus, this second perspective focuses on the role of university

incubators in technology transfer and the commercialisation of research results.

The approach that considers university incubators as drivers of creating an entrepreneurial ecosystem is also widely recognised. Dániel and Porkoláb (2021) explain that university incubators contribute to establishing a dynamic network of economic actors, including entrepreneurs, investors, researchers and academic institutions. These structures facilitate interactions and collaborations, thus stimulating innovation and local economic growth (Siddiqui et al., 2021; Osiobe & Winingham, 2020; Gorączkowska, 2020).

Despite the variations in the definitions of university incubators, several core elements emerge. Firstly, incubators provide a dedicated physical or virtual space designed to welcome and support project leaders. Additionally, incubators offer a comprehensive set of services, including shared office spaces, technical equipment, personalised support, and access to a network of mentors and experts. These services are tailored to address the specific needs of start-ups and facilitate their development. Furthermore, incubators play a pivotal role in fostering a vibrant community of entrepreneurs, researchers, and investors, which enhances collaboration and promotes the exchange of ideas. Finally, incubators have a mission to add value to university research results by encouraging the commercialisation of innovative ideas and supporting the creation of new businesses. This multifaceted approach underscores the integral incubators' role in bridging the gap between academic research and industry (Hassan, 2020; Etzkowitz, 2016).

1.2. Distinctive traits of university incubators

University incubators tend to operate differently from other types of incubators on several points raised in this section. But first, it must be recognised that university incubators are also heterogeneous and diversified, hence the attempts of some researchers to classify them into reasoned typologies.

Clarysse et al. (2005) proposed one of the first classifications of university incubators by considering three criteria: field of activities (opportunity search, IP protection, strategy, business planning, funding, and spin-out); resources employed (organisation, human resources, technology, physical resources, finance, and network); and reference models (strategies and outcomes). Criticising this and other classifications for being too general and incorporating the attributes of these incubators that are overlooked in the previous typologies, Nicholls et al. (2020) developed a more detailed typology based on the following dimensions: stakeholders, objectives, strategic focus, incubation process, resources and services, and socio-economic impacts. This typology is based on six main dimensions that are in turn subdivided into 17 sub-dimensions (dominant logic, outputs, target scope, business model, structure, infrastructure, networking, capital, and culture), which define the scope of each dimension to clearly reveal the heterogeneity of university incubators. As university incubators are heterogeneous, it is time to analyse the specific features that distinguish them from other types of incubators.

In many ways, university incubators are similar to traditional incubators. However, they tend to operate differently in a few respects due to how they were created and operated (Pellegrini & Johnson-Sheehan, 2020). First, compared to other incubators, university incubators are mainly set up for technology dissemination and transfer (Adriansyah & Rimadias, 2023; Hassan, 2020). In this regard, Dániel and Porkoláb (2021) confirmed that university incubators have adequate experience in terms of human expertise, funding sources, location on or near university campuses, focus on innovation and product commercialisation.

Second, Pellegrini and Johnson-Sheehan (2020) considered that the main difference between university incubators and other incubation structures is the support approach in terms of duration and nature. They are designed to offer long-term support to enable the companies created to remain and develop within the university ecosystem. By contrast, non-university incubators focus on short-term support and transition to other forms of support.

Third, it is argued that university incubators can help start-ups increase their legitimacy by reducing transaction costs through location under the university umbrella (Chan & Lau, 2005). They benefit from similar services offered by other incubators (offices, administrative services, equipment, etc.), in addition to access to the university's infrastructure for facilities, support staff, equipment and services, while leveraging the university's reputation (Adriansyah & Rimadias, 2023; Siddiqui et al., 2021).

Fourth, university incubators are generally funded by universities, whereas most business incubators are funded by potential investors and charge their tenants for services (Pellegrini & Johnson-

Sheehan, 2020). Indeed, a key decision for university incubators is how to obtain resources and turn them into services. To this end, Somsuk and Laosirihongthong (2014) have listed university incubator resources in four main categories: human, financial, organisational, and technological resources.

Fifth, the profile of the entrepreneurs hosted is another aspect that differentiates incubators. In the case of university incubators, it is mostly professors, researchers, and students who have the advantage of undertaking less risk (professors already have a source of income, and students can more easily enter or re-enter the job market) than other entrepreneurs who often face greater financial and career risks (Pellegrini & Johnson-Sheehan, 2020). However, these profiles can act as barriers to entrepreneurship because of the contradictions between academic and industrial cultures (Adriansyah & Rimadias, 2023; Clarysse et al., 2005; Hidayati et al., 2018): the former focuses on research, publication and the advancement of knowledge, while the latter focuses on the practical application of innovations, profitability and commercial results.

These various traits of university incubators are not exhaustive, but they provide valuable insight into how they operate and the key elements that contribute to their success. By examining these characteristics, we can better understand the factors that drive their effectiveness. While there are other potential determinants at play, these traits offer a starting point for identifying the most critical factors that impact the performance of university incubators.

1.3. Performance measurement in university incubators

The literature on measuring the performance of university incubators explores various frameworks and methods for assessing their effectiveness, impact and contribution to the entrepreneurial ecosystem. This section focuses on theoretical and empirical approaches to measuring the performance of university incubators, highlighting key criteria and associated challenges.

Over the past forty years, numerous studies have examined the question of incubator performance (Fakhri et al., 2023). Nevertheless, it is clear that they have not reached a consensus on how to apprehend this performance: efficient use of resources, business and job creation, incubatee satisfaction, and multidimensional measure combining multiple criteria (Vanderstraeten et al., 2012). This complexity is likely to be amplified in the case of university incubators due to the specificities of the university environment (Gozali et al., 2020).

Mian (1997) was one of the first to propose a comprehensive, integrated model of university incubator performance. His starting point is the scarcity, fragmented nature, and controversy surrounding the data on the contribution of university incubators to the development of technology-based start-ups in the USA. Thus, adopting an integrative approach, he conducts a study combining available knowledge on incubation activity, the university's contribution to technology transfer, and commonly accepted approaches to organisational evaluation. The model is broken down into three performance dimensions: (a) incubation results (sustainability and growth of the programme, survival and growth of the tenant company, contributions to the mission of the sponsoring university, and impacts on the community); (b) management policies and their effectiveness; and (c) services offered and their added value.

While acknowledging the merit of Mian's (1997) model for benchmarking incubator performance, Chan and Lau (2005) consider it inappropriate for evaluating an incubation programme from the perspective of incubated companies throughout their development process. They propose a set of indicators to measure incubator performance: advantages from pooling resources, sharing resources, consulting services, positive effect from higher public image, networking advantages, clustering effect, geographic proximity, cost subsidies, and funding support. The most obvious limitation of this model is its one-dimensional nature, associating an incubator's performance with the incubation process alone without considering the role of internal and external stakeholders.

Based on factors identified in the literature and a preliminary study with expert professors affiliated with world-renowned universities, Gozali et al. (2020) proposed a new explanatory framework for incubator performance in public universities in Indonesia. They propose a six-factor model including age and quality of facilities, credits and awards, entry criteria, exit criteria, financial support, a good system, and good infrastructure.

Conducting a similar study among Thai university incubators, Yamockul et al. (2019) identified four main practices influencing university incubator performance: (a) practice in management and administration of the incubators; (b) practice in supporting services provided to incubatees; (c) practice in aug-

mented services for technopreneur incubation, and (d) practice in the selection of potential incubatees.

Siddiqui et al. (2021) believed that the work of Gozali et al. (2020) has methodological issues, while that of Yamockul et al. (2019) is based on students' entrepreneurial intentions and not on actual incubator experience. They try to consider these limits and propose a framework of critical success factors for university business incubators that culminates into five big factors: (a) support services, (b) network support, (c) financial support, (d) economic development, and (e) alumni success. The results of their study show that, ten years after their launch in Saudi Arabia, university incubators still face difficulties in obtaining funding and bureaucratic requirements from the government. In addition, they recommend a great deal of comprehensive awareness-raising among students to enhance their knowledge and develop entrepreneurial passion. These findings are similar to those formulated by Ruiz Navarro et al. (2017) in their study of Moroccan Universities and Entrepreneurship.

A review of these various studies indicated the multidimensional nature of university incubator performance involving various factors and interactions. This complexity reinforces the relevance of the current study, particularly in the Moroccan context, where such dynamics may differ from those in other regions of the world.

2. Methodology

2.1. Research design

This research adopts a qualitative approach to explore the determinants of university incubator performance in Morocco. In qualitative research, one major challenge is deciding whether to analyse a single case or several. According to Miles and Huberman (2003), examining several cases enables the researcher to discover divergent cases, reinforcing the theory developed by confronting similarities and differences.

A multiple case study was chosen, which focused on six university incubators, to gain an in-depth and nuanced understanding of the factors influencing their performance. According to Yin (2017), multiple case studies enable the characteristics of the units studied to be compared and contrasted, offering a more holistic view of the themes investigated. Thus, this methodology, favoured in exploratory research (Eisenhardt, 1989), will help analyse the specific contexts of each incubator while allowing for limited comparisons and generalisations due to the relatively new and understudied nature of the subject in Morocco.

2.2. Data collection methods

Six university incubators were selected according to criteria specific to the university context to ensure that the sample was adequately representative. These criteria included the geographical location of the universities to cover different regions of Morocco. We also considered the current presence of active incubatees, choosing incubators that host start-ups or projects under development, enabling us to obtain relevant information on current incubation practices. In addition, we selected incubators with a track record of business creation, i.e., incubators that have already produced companies. The types of support programmes offered were also a selection criterion, including those offering various supports such as mentoring, training, financing, and networking. Finally, we considered incubators' academic and industrial partnerships, selecting those that collaborate with other academic institutions, companies, and government organisations to explore the impact of these collaborations on incubator performance. These criteria enable us to cover a wide range of characteristics and contexts, offering a comprehensive perspective on the determinants of university incubator performance in Morocco.

A combination of documentary methods and semi-structured interviews were used to collect the data required for the study. Miles and Huberman (2003) encouraged researchers to triangulate data from multiple sources to gain a fuller understanding of the subject under study and strengthen the credibility of qualitative research findings.

Yin (2017) considered documentary analysis essential for case study researchers, as it enables them to explore in depth the historical, contextual, and organisational aspects of the cases studied. In the current study, a structured form was used to systematically extract and analyse relevant documents, such as academic literature, institutional reports, public policies and internal documents of university incubators.

At the same time, according to Miles and Huberman (2003), interviews are a valuable means of obtaining in-depth perspectives and experiences from participants. They stress the need for active listening and the creation of a relationship of trust with

Tab. 1. Data sources

Incubator	Analysed Documents	Number and Profiles of Interviews
1	Annual report, business plans, sector studies, website content	5 interviews: 3 incubatees, 1 incubator director, 1 funder
2	Activity reports, public policy documents, flyers, communication materials	4 interviews: 2 incubatees, 1 incubator director, 1 expert
3	Strategic plans, internal reports, guide of procedures	3 interviews: 1 incubatee, 1 incubator director, 1 coach
4	Sector studies, academic literature, website content, internal reports,	5 interviews: 2 incubatees, 1 funder, 1 coach, 1 university officials
5	Business model templates, annual reports, communication documents	4 interviews: 1 laureate, 1 incubator director, 1 university official, 1 expert
6	Reports on regional impact, funding guidelines, flyers	3 interviews: 1 laureate, 1 funder, 1 coach

interviewees to enable participants to fully express their thoughts and experiences. Twenty-four semi-structured interviews were conducted with incubator managers, incubated entrepreneurs, funders, incubation experts, and university managers.

2.3. Data analysis

The data used in this study are primary and secondary. Primary data are obtained from interviews with various players and stakeholders in university incubators. Secondary data are obtained and collected from literature reviews, activity reports of incubators and universities, institutional reports (ministry bodies), and websites.

Regarding the primary data, the 24 interviews conducted are first carefully recorded to ensure a complete and accurate capture of the exchanges. After recording, each interview is transcribed in full, providing a faithful text of the discussions held. This transcription forms the basis of the qualitative data to be analysed.

For secondary data, documentary analysis is carried out in parallel with interview analysis. It starts by drawing up a detailed document analysis guide, including document selection criteria, specific research questions, and themes and categories to be explored. The selected documents are then imported into NVivo 12, a qualitative analysis software, for systematic processing.

This qualitative analysis software enables systematic coding of the transcripts, facilitating data organisation and exploration. In this way, thematic codes can be applied to the various interview segments and documentary analysis, identify recurring patterns, and explore relationships between emerging themes. This method enables triangulating the results of the documentary analysis with those of the interviews, thus reinforcing the validity of conclusions (Miles & Huberman, 2003). In addition, this approach ensures a certain objectivity in the analysis and facilitates comparison between different data sources.

3. Results

3.1. Emergence of university incubators in Morocco

Law No. 01-00 on organising higher education in Morocco has opened up new prospects for Moroccan universities, providing them with the legal framework they need to strengthen their entrepreneurial activities and contribute to the country's socio-economic development. They now have the possibility of setting up structures to bring the business world closer to them, thereby enhancing the value of their research results. Indeed, article 7 of this law recognises the entrepreneurial mission of universities, stipulating that "within the framework of the missions assigned to them by the present law, universities may, by agreement, provide services for remuneration, create incubators for innovative companies, exploits patents and licenses, and market the products of their activities".

Since then, efforts have been made by central authorities and universities to set up programmes and structures, such as university incubators, to promote the valorisation of research results and innovation. In this context, the Moroccan Incubation and Spin-Off Network was launched in 2002 to promote the valorisation of scientific research results, encourage innovation and the creation of innovative companies, and develop an entrepreneurial dynamic in university and research circles.

This programme has supported the incubation of 81 projects, only 23 of which have gone on to become

start-ups. Difficulties encountered include the lack of autonomy and human resources for incubators at the university level, the lack of a favourable legal framework due to the absence of texts implementing the provisions of Law No. 01-00, and cumbersome financial and administrative procedures. Based on this experience, a more ambitious programme is underway with the creation of Innovation Cities.

3.2. Organisation and operation of university incubators

The Moroccan Incubation and Spin-off Network (RMIE) Terms of Reference propose two forms of organisation for carrying out the mission of creating innovative companies: first, focusing on technological and scientific aspects, and second, more general, encompassing all aspects of support.

Although the organisation of university incubators varies considerably, the interviews revealed two predominant configurations. In the first scenario, incubators are placed under the responsibility of project managers, often lecturers appointed by university presidents, who maintain a direct relationship with the university institution hosting them. In a second scenario, some incubators are managed at the Innovation City level, reporting directly to the Innovation City hierarchy or to the university president.

The organisation of university incubators seems to be closely linked to the university itself. They can be seen as internal university services, which can facilitate access to university resources. Some university incubators have steering committees that define overall strategy, objectives and scope of activity. However, it is noted that these committees do not necessarily follow a vertical hierarchy, but rather a cross-functional, project-based approach.

Despite their varying sizes, the six university incubators in our study generally have adequate space to accommodate incubated projects, reflecting a supply adapted to demand. They are strategically located within or close to university establishments, particularly those in the hard sciences, to facilitate direct access to laboratories and scientific research platforms.

An analysis of the services offered by these university incubators reveals a remarkable convergence in the offerings and philosophy of support for incubatees. Despite the differences in size, a basic set of services is widely offered to support projects. Essential services include office space, internet connection, meeting rooms, and coworking spaces to facilitate collaboration. Beyond the physical infrastructure, training, management consulting and support services are also offered to help incubatees improve their entrepreneurial skills and develop their ideas.

3.3. Perceived performance of university incubators

The theme of university incubator performance is explored through the responses of 24 respondents. They represent a variety of perspectives, including funders, incubator managers and staff, incubation experts and project owners. This diversity of viewpoints is likely to present a comprehensive view of how performance is perceived in the context of university incubators.

Representatives of funding organisations generally recognise the essential role incubators play in promoting entrepreneurship. They believe that performance depends on several factors, including the specific context of each incubator. However, they emphasise that performance can vary from one incubator to another, depending on their objectives and available resources.

Managers and staff of incubators and universities, on the other hand, express mixed views. While some consider that their incubators are performing well despite the constraints they face, others feel that a lack of resources limits their level of performance. They also stress the need for adequate resources to achieve the desired performance.

Experts acknowledge that incubators have made progress but feel there is still room for improvement. They consider that university incubators are on the right track. Nevertheless, they must develop business expertise and collaborate more with the entrepreneurial ecosystem to reach their full potential. On the other hand, project owners have varying opinions on the performance of incubators. Some consider that incubators perform well, while others feel they can do better by overcoming recurring problems.

The perceptions of the various players regarding the level of performance of university incubators in Morocco vary according to the categories of respondents and their personal experiences in the field. While these perspectives may differ, a consensus on the challenges and constraints encountered is emerging. First, the current model does not always seem suited to the early stages of entrepreneurial projects, with an urgent need to clarify the different support phases,

Tab. 2. Perceptions of university incubator performance by respondent category

Respondent Category	Positive Perception of Performance	Mixed Perception of Performance	Negative Perception of Performance
Funders	33 %	67 %	0 %
Incubator Directors, University Officials & Coaches	56 %	33 %	11 %
Experts	50 %	50 %	0 %
Incubatees & Laureates	50 %	40 %	10 %

Tab. 3. Frequency of determinants discussed by different stakeholders

	Incubator Directors, University Officials & Coaches	Incubatees & Laureates	Funders	Experts
Incubatee characteristics	89 %	80 %	100 %	50 %
Access to funding	100 %	70 %	100 %	100 %
Governance	89 %	60 %	100 %	100 %
Selection practices	33 %	10 %	67 %	50 %
University regulations	89 %	60 %	100 %	100 %
Networks	100 %	90 %	67 %	100 %
Human resources	100 %	90 %	100 %	100 %
Services and available infrastructure	100 %	90 %	100 %	100 %
Government support	89 %	60 %	67 %	50 %
Specialisation	33 %	20 %	0 %	100 %

from pre-incubation to incubation. The lack of qualified and motivated mentors is also a significant obstacle, compounded by the lack of mature, innovative projects and truly committed incubatees. In addition, the bureaucratic system, while necessary, often hinders the agile management of incubators. Difficult access to financing and red tape are recurring obstacles exacerbated by the absence of legislation and appropriate structures, such as implementing regulations for Law No. 01-00 or mechanisms for participatory financing and business angels. There are also governance problems, notably the lack of autonomy of incubators from universities, which complicates budget management and the involvement of the private sector. Incubators also suffer from a lack of local prototyping infrastructure and stable human resources, which can undermine the continuity and effectiveness of projects. Finally, university training courses often focus on entrepreneurial culture without offering the technical skills needed to create innovative businesses, which limits the potential of incubated projects.

The perspectives of various stakeholders involved in the incubation process were analysed to further understand the determinants of university incubator performance. Table 3 provides a breakdown of the frequency with which different themes were discussed during interviews with funders, incubator managers, entrepreneurs, and experts. These themes reflect the major factors that influence the success and challenges faced by university incubators in Morocco. These determinants will be discussed in detail in the next section.

4. Discussion

Based on the thematic content analysis (literature review and semi-structured interviews), various determinants of university incubator performance in Morocco were identified, which were split into three categories as proposed by Sun et al. (2007): those relating to the incubator, the incubatee, and the environment.

4.1. Determinants relating to the incubator

The thematic content analysis reveals several determinants of university incubator performance and their ability to stimulate innovation and entrepreneurship in Moroccan universities. This approach underlines various internal factors, such as services offered, available infrastructure, governance, selection practices, and human resources.

First, the governance of university incubators is a key factor in their performance. That means having a clear mission and vision, an appropriate structure with well-defined management bodies, and a flexible, adaptable organisation. This observation is confirmed by several studies that have raised the importance of governance in ensuring incubator performance (Adriansyah & Rimadias, 2023; Siddiqui et al., 2021; Sun et al., 2007). The analysis also shows that the services offered and the facilities available are fundamental aspects influencing the activities of university incubators and, therefore, their performance. Physical facilities, such as premises, scientific equipment and workspaces, are essential for creating an environment conducive to entrepreneurs' creativity and productivity. In addition, personalised support services, such as training and access to academic expertise, play a decisive role in the success of incubators in the university context.

In addition, the availability of skilled, varied, and dedicated human resources is important for providing quality support that meets the needs and expectations of all stakeholders (Gozali et al., 2020). The involvement of experts, mentors and experienced advisors is essential to guide entrepreneurs along their journey. The development and professionalisation of human resources, aligned with the objectives of each incubator, are necessary to guarantee their performance (Siddiqui et al., 2021; Hassan, 2020; Somsuk & Laosirihongthong, 2014).

The analysis also revealed that given the quantity of resources available, clear selection criteria and rigorous evaluation enable incubators to admit promising projects, thereby optimising their performance (Gozali et al., 2020). However, a balance between selectivity and openness to new opportunities must be struck, as overly strict selection policies could exclude innovative ideas.

Therefore, a significant new dimension revealed by the analysis of interview responses is the specialisation of incubators. This specialisation makes more efficient use of limited resources and fosters innovation by responding in a targeted way to specific needs. This approach aligns with the findings of previous studies that highlight the benefits of specialisation for incubator performance (Dániel & Porkoláb, 2021; Chan & Lau, 2005).

4.2. Determinants relating to the incubator environment

The thematic analysis carried out on documents and interviews enables the identification of the main environmental determinants of the performance of Moroccan university incubators. By focusing on factors such as government support, networks, university regulations, and access to funding, this study underlines the importance of the external environment in the development and success of these structures. These factors are not isolated variables but form part of a complex system in which each element influences and is influenced by the others.

The availability of funding emerges as a central factor in the performance of university incubators. Although efforts have been made to improve access to funding, respondents point to a lack of funds specifically dedicated to university entrepreneurs. Access to adequate funding is crucial to the development and growth of incubated start-ups and the fulfilment of incubator missions. Despite improvements in access to funding, challenges remain, including the reluctance of banks, the need to revitalise programmes such as RMIE, and the creation of financing tailored to innovative projects. These findings confirm the results of various studies (Gozali et al., 2020; Somsuk & Laosirihongthong, 2014), reinforcing the validity of observations and contributing to the continued research progress in this field.

Government support is also a major determinant of the performance of university incubators (Kulkarni et al., 2024; Hassan, 2020; Sun et al., 2007). Study respondents claimed that government policies and initiatives, such as tax incentives, subsidies, specific funding programmes, intellectual property services, and administrative facilitation, are essential to encourage business creation and support university incubators in their missions.

Another important determinant identified is the availability of networks. The analysis revealed that networking plays a key role in the performance of university incubators. Collaborations with various ecosystem actors, diversification of networks, entre-

preneurial education, and community support are essential to sustain incubated projects. By consolidating partnerships and fostering collaboration within the entrepreneurial ecosystem, incubators can improve their effectiveness and impact on entrepreneurial development (Siddiqui et al., 2021; Dániel & Porkoláb, 2021).

Finally, analysis of the interviewees' feedback and activity reports reveals that university regulations present several significant challenges to incubator performance. Administrative complexities, bureaucracy and regulatory rigidity hamper incubator operations by generating delays and limiting resources due to budget constraints and complex financial management processes. Regulatory changes are needed to recognise and support the entrepreneurial commitment of students and researchers through dedicated academic modules and formal recognition of entrepreneurship in university curricula.

In conclusion, analysis of the environmental determinants of university incubator performance offers valuable insights into the external factors influencing their effectiveness. These elements are essential to guide actions aimed at optimising the operation of incubators and maximising their contribution to innovation and entrepreneurship within academic institutions.

4.3. Determinants relating to the incubatee

Adriansyah and Rimadias (2023) underlined the specificity of university incubators compared to other types of incubators, emphasising the critical role played by the academic community, which includes lecturers, students, and alumni. This community is not only a valuable source of expertise but also serves as a network of business connections and a source of essential support for incubatees. The involvement of the academic community in UBIs offers unique advantages, as it creates an environment where knowledge, innovation, and entrepreneurial spirit can be shared and nurtured. In addition, self-employment serves as a means of creative expression and identity formation while also fostering community altruism and leveraging cultural capital, promoting economic development and enhancing the performance of university incubators (Osiobe & Winingham, 2020).

In line with this, Sun et al. (2007) recognised that incubatee characters and backgrounds (education and experience) are critical factors in incubator performance. Indeed, the results of the current study underline the preponderant role of incubatee skills and attitudes in the performance of university incubators. Essential traits identified include motivation, passion, commitment, perseverance, and adaptability, including openness to change and acceptance of advice. Other aspects, such as training, entrepreneurial skills and experience, are also important for success in these environments.

These elements underline the fact that incubatees need certain personal qualities, technical skills, and practical experience to take full advantage of the opportunities offered by incubators.

Interviewee statements confirmed that motivation and passion, e.g., strengthen the determination to overcome the challenges encountered during the incubation phase. Commitment and perseverance enable incubatees to stay on course in the face of obstacles, while adaptability ensures an effective response to advice and unforeseen changes. At the same time, adequate training and entrepreneurial skills provide the foundations for developing effective strategies and bringing projects to fruition. Previous experience, meanwhile, enriches the ability to thrive in complex environments and avoid common mistakes.

This thematic content analysis of documents and semi-structured interviews revealed a nuanced understanding of the factors influencing the performance of university incubators in Morocco. The study categorises these determinants into three primary areas (those related to the incubator itself, the incubatee, and the external environment) and offers a framework for understanding and enhancing the effectiveness of university incubators in fostering innovation and entrepreneurship. In discussing these various factors, the findings pave the way for different stakeholders to develop targeted strategies and make informed decisions. For instance, incubatees can use this information to identify and select the most effective incubators that align with their needs and goals. Funders, on the other hand, can leverage these insights to determine which incubators are most worthy of financial support, ensuring that their investments are directed towards entities with a proven track record of success. Furthermore, incubator managers will gain a clear understanding of the key elements that require attention and improvement, enabling them to enhance the overall performance and impact of their programmes.

Conclusions

Based on an in-depth thematic analysis, this study has helped to enrich knowledge of the determinants of university incubator performance in the Moroccan context. The results emphasise the importance of a multidimensional approach that considers internal, external, and incubatee-related factors. By acting on these different levers, it is possible to optimise the role of incubators in promoting innovation and business creation in Morocco.

From a scientific point of view, this study contributes to the existing literature on university incubators by exploring the determinants of their performance in the context of an underdeveloped country. By analysing these determinants, this research confirms and extends existing theories on the subject. The results corroborate previous studies on the importance of internal and external factors when evaluating incubator effectiveness. The appearance of specialisation as a potential lever for optimising incubator resources and responding more effectively to entrepreneur needs opens up new avenues for research. Finally, incubators need to pay particular attention to the characteristics of their incubatees. A rigorous selection process, accompanied by personalised support, is essential to maximise the chances of success for entrepreneurial projects.

From a practical point of view, the findings of this study offer valuable insights for policymakers, university administrators, and incubator managers in Morocco. The results can help to improve the effectiveness of university incubators in fostering innovation, job creation, and economic development in Morocco by highlighting the importance of creating a supportive environment for university incubators.

The results of this study answer the question asked on the performance of Moroccan university incubators. However, the sample of incubators studied is relatively small, which limits the generalisability of the results. For future work, the authors will consider conducting longitudinal studies to better understand the evolution of incubator performance over time and to explore in more detail the impact of public policies and funding mechanisms on incubator outcomes. An international comparison could also offer additional perspectives into best practices and effective strategies for supporting academic entrepreneurship.

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Service model of smart tourism cities integrated with low-altitude technology

Tian Yang Luo

ABSTRACT

The purpose of this study is to propose a comprehensive service model for integrating low-altitude technology into Guangzhou's smart tourism ecosystem. This model aims to address the critical technological, operational, and governance challenges faced by urban tourism systems, providing a scalable framework to enhance operational efficiency, visitor satisfaction, and collaborative management. The study employs a theoretical approach by developing a three-layered service model based on extensive literature analysis, policy review, and case studies of drone applications in tourism. The model comprises the Core Technology Layer, Service Application Layer, and Governance and Collaboration Layer, each of which incorporates specific influencing factors, such as R&D investments, operational efficiency, and policy support. The research identifies the critical role of low-altitude technology, including drones, AI, IoT, and big data platforms, in transforming urban tourism systems. The findings demonstrate how real-time data processing and seamless governance can enhance tourism services, such as monitoring, emergency response, and immersive experiences. Additionally, the study highlights the importance of collaboration among policymakers, businesses, and stakeholders in ensuring the sustainable implementation of low-altitude technology. This paper advances the theoretical understanding of integrating low-altitude technology into smart tourism cities by developing a structured service model. It enriches the academic discourse on urban tourism by addressing the interplay between technological innovation, service delivery, and regulatory frameworks, providing a foundational framework for future research. The proposed service model offers actionable insights for policymakers, urban planners, and businesses in Guangzhou and other urban tourism cities. By aligning technological infrastructure with service delivery and governance, the model provides a roadmap for improving operational efficiency, enhancing visitor experiences, and fostering public-private partnerships. It also offers guidance for addressing key challenges such as regulatory barriers, public acceptance, and cost-benefit considerations, paving the way for more efficient and sustainable tourism systems.

KEY WORDS

service model, smart tourism, low-altitude technology

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Introduction

With the continuous advancement of global smart city construction, smart tourism cities, as a type of smart city, are gradually becoming a key direction for the deep integration of the tourism industry and information technology (Buhalis & Amaranggana, 2015). By leveraging advanced technologies, such as the Internet of Things, big data, and artificial intelligence, smart tourism cities provide convenient, efficient, and personalised services to tourists while also enhancing the management and operational efficiency of urban tourism resources.

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However, existing smart tourism cities face challenges in cross-regional coordination, spatial expansion, and comprehensive management capabilities. Traditional technical approaches struggle to fully meet the diverse needs of modern tourists (Sevilla-Sevilla et al., 2024). Therefore, there is an urgent need to introduce innovative technologies to optimise service models and enhance the overall competitiveness of urban tourism.

In recent years, the rapid development of low-altitude technology has provided new technical means and service ideas for smart tourism cities. Low-altitude technology is centred on drones and general aviation. It enables data collection, real-time monitoring, and innovative tourist services in urban airspace (Abeyratne, 2018). However, the application of these technologies in urban contexts has yet to achieve large-scale implementation and remains in the pilot stage (Foina et al., 2015). For instance, in Shenzhen, drone technology has been used in smart tourism cities for traffic monitoring and landscape promotion. It allows for the rapid collection of real-time imagery from major urban attractions and surrounding areas, which is applied in city tourism branding and traffic flow analysis. Nevertheless, this has yet to be fully integrated into a holistic smart tourism service system. Similarly, Fukuoka, Japan, is exploring low-altitude technology for urban panoramic tours and nighttime light shows, utilising coordinated drone flights to enhance tourist experiences. However, the service scope and business model remain in the early exploratory stages.

Moreover, despite significant persistent challenges, low-altitude technology demonstrates potential in urban emergency services and resource management (Boucher, 2016). The West Lake Smart Tourism Zone in Hangzhou, China, has proposed using drones for tourist flow management and emergency rescue. However, at the city level, a comprehensive operational standard and technical support system have yet to be established (Erdelj et al., 2017). In Amsterdam, the Netherlands, low-altitude technology has been piloted to monitor real-time tourist movement and traffic conditions at key urban tourism nodes. Yet, issues such as flight safety in densely populated urban areas and regulatory restrictions have hindered large-scale deployment. These cases highlight the significant potential of low-altitude technology in smart tourism cities while revealing limitations in scalability, systematic integration, and challenges related to technology, policy, and costs.

As one of China's most vibrant and rapidly developing urban centres, Guangzhou has demonstrated a strong demand for the integration of low-altitude technology and smart tourism systems. Guangzhou's rich cultural heritage and diverse tourist attractions, such as the Canton Tower, Pearl River, and numerous historical sites, attract millions of visitors annually. However, the city faces significant challenges in managing increasing tourist flows, optimising resource allocation, and maintaining sustainable urban development. Current tourism management systems often lack the capacity for real-time data analysis, dynamic resource management, and comprehensive service integration, which are essential to meet the expectations of tech-savvy tourists. Moreover, regulatory bottlenecks, fragmented governance structures, and a lack of standardised technical frameworks for the deployment of low-altitude technology have hindered the widespread adoption of drones and related innovations in Guangzhou's tourism sector.

Based on the above background, this study addresses the academic issue of systematic insufficiency in the integration of smart tourism cities with low-altitude technologies, focusing on the current technological limitations of smart tourism cities in terms of tourist flow management, real-time monitoring, resource deployment, and emergency response. Despite the potential value of low-altitude technologies, such as drones, the Internet of Things (IoT), big data, and Artificial Intelligence (AI) in smart tourism, the existing research lacks a systematic technology integration framework and focuses mainly on single-scenario applications at the expense of cross-scenario synergy, technology interoperability, and the construction of city-level governance systems. In addition, current low-altitude technologies still have many challenges in terms of smart tourism policy regulation, data security, and public acceptance, making it difficult to effectively assess the feasibility and sustainability of technology applications. This study specifically focuses on the empirical research on the integration of low-altitude technology for smart tourism city development in Guangzhou and addresses the following two main research questions:

- What is the actual situation of Guangzhou's utilisation of low-altitude technology to develop urban construction? What are the problems?
- What are the potential application pathways of low-altitude technology in resource monitoring, tourist services, risk forecasting, and emergency

management, and how can these be systematically integrated into a new service system for smart tourism cities?

This study focuses on the need for service model innovation in smart tourism cities, addressing the limitations of existing models in terms of innovation and efficiency optimisation. It proposes integrating low-altitude technology into the service models of smart tourism cities. The theoretical significance of this research lies in expanding the research boundaries of the smart tourism field and providing a theoretical foundation for exploring the application of low-altitude technology in urban-level tourism management and services. Its practical significance lies in offering specific implementation plans and optimisation strategies for the construction of smart tourism cities, promoting the digital transformation of the tourism industry and innovation in service models. In summary, this study uses low-altitude technology as a focal point to provide new perspectives and development strategies for the construction of smart tourism cities.

1. Literature review

1.1. Research on smart tourism city

A smart city is a city that improves the efficiency of city management, enhances the quality of life of residents and realises sustainable development through information technology and digital means (Angelidou, 2014). The core features of smart cities include the widespread application of technologies, such as big data analytics, the Internet of Things (IoT), cloud computing, and artificial intelligence (AI), to help cities optimise in areas such as traffic management, energy use, public safety, and environmental monitoring (Anthopoulos, 2015). Smart cities aim to improve the level of intelligence and automation of all city services through the innovative integration of technologies to cope with increasingly complex urbanisation (Gretzel et al., 2015). The combination of these technologies makes cities more efficient and intelligent in terms of resource allocation, emergency response, and citizen services.

A smart tourism city is an important part of a smart city, focusing on utilising modern technology to enhance the overall service level and management efficiency of the tourism industry (Lee et al., 2020). Smart tourism city refers to the full use of modern information technology, especially big data, artificial intelligence, the Internet of Things and cloud computing, in the process of city management and tourism industry development to improve the management efficiency of the city, optimise the visitor experience as well as promote sustainable development. A smart tourism city is not just a digital transformation based on traditional city services, it also creates a smarter, more personalised and sustainable tourism environment through deep integration of technologies (Baggio et al., 2020).

When defining a smart tourism city, it is necessary to focus on its core functions: first, intelligent visitor services, which are achieved by providing tourists with real-time information, personalised travel recommendations, smart tour guides and other services. Second is the efficient management of tourism resources. Smart tourism cities rely on big data analytics and IoT technologies to optimise attraction flows, resource allocation, and emergency response, thereby improving resource utilisation and reducing pressure during peak periods (Um & Chung, 2019; Chung et al., 2021). Furthermore, smart tourism cities need to enhance their comprehensive city management capability through information technology, such as effective management in the areas of transportation, public safety, and environmental monitoring.

However, most of the existing smart tourism city research focuses on the optimisation of tourists' experience and neglects the deep integration at the city management level, especially in the application and coordination of cross-scenario technologies. The limitation of existing studies is demonstrated by the fact that many of them do not comprehensively explore how smart tourism cities can achieve city-level integrated coordination and management through technological innovation (Del Chiappa & Baggio, 2015). Therefore, integrating low-altitude technology with other management systems of smart tourism cities, aiming to improve the overall service quality and efficiency of the city, has become an important issue in the current research on smart tourism cities.

1.2. Research on low-altitude technology

Low-altitude technology refers to the use of technologies, such as unmanned aerial vehicles (UAVs), unmanned aerial vehicles (UAVs), and urban air traffic systems (UAMs), for data collection, monitoring, transportation, and other services, especially in urban airspace. These technologies can provide new perspectives for urban management, especially playing an

important role in traffic monitoring, environmental monitoring, and emergency response (Abeyratne, 2018). The wide application of low-altitude technologies enhances the intelligent management capability of cities and shows great potential in improving the quality of urban public services, improving emergency response speed, and enhancing the experience of tourists.

The market applications of low-altitude technology have undergone gradual expansion from the military domain to the civilian market. Early studies primarily focused on optimising the hardware performance of drones, such as flight stability, endurance, and payload capacity, laying the foundation for drones' entry into the commercial sector (Giones & Brem, 2017). With the continuous maturation of the technology, drones have been widely applied in agriculture, environmental monitoring, and infrastructure inspection, demonstrating significant economic and social value. However, many studies focus on the technological development of drones while lacking in-depth analysis of their functional integration and application effectiveness in complex scenarios. For example, Kellermann et al. (2020) pointed out that while drones improve efficiency in agriculture and logistics, regulatory restrictions and a lack of operational standards hinder their large-scale adoption in the industry.

As drones entered the service sector, their applications gradually expanded to such industries as media, entertainment, and logistics (Askerbekov et al., 2024). In recent years, their potential in tourism and urban management has garnered increasing attention, with applications in such scenarios as urban landscape aerial photography, real-time traffic monitoring, and tourist flow management. However, existing studies often focus on exploring the technological possibilities without addressing the integrated application of low-altitude technology at the urban level. For instance, Floreano and Wood (2015) highlighted the significant challenges for drones operating in densely populated urban environments, where stringent requirements for flight safety exceed the current technological capabilities. Additionally, most studies emphasise the single-function applications of drones and fail to propose systematic solutions, limiting their role in smart cities to certain specific scenarios (Li, 2023).

Although drone technology has entered the research scope of smart city construction in recent years, its practical application still faces challenges. Current studies provide insufficient discussions on the scalability and operational standardisation of low-altitude technology, which restricts the large-scale adoption of drones (He et al., 2022; Eshtaiwi & Ahmed, 2024; Huang et al., 2024). On the other hand, there is a lack of evaluation of the effectiveness of low-altitude technology in the service sector. For example, while research emphasises the advantages of drones in monitoring, emergency response, and tourism, empirical data supporting these applications' actual value is scarce (Jiang et al., 2025; Madden et al., 2022; Ayamga et al., 2021). This indicates an urgent need for more systematic and comprehensive analysis to address the complex demands of urban environments as low-altitude technology enters the field of smart tourism.

1.3. Research progress on the integration of smart city construction and low-altitude technology

The literature widely acknowledges the significant potential of low-altitude technology in smart cities, particularly in traffic management, environmental monitoring, and public safety (Huang et al., 2024). Studies have shown that low-altitude technology can significantly enhance the efficiency of traffic flow monitoring, especially in large urban areas. UAVs can collect real-time traffic data, enabling transportation management departments to quickly identify traffic bottlenecks and accidents, which helps in optimising traffic signals and resource allocation (Wang et al., 2020). In environmental monitoring, UAVs have been successfully applied for air quality monitoring, pollution source tracking, and assessing urban environmental health. These capabilities provide city managers with efficient tools for monitoring and responding to urban sustainability challenges (Madden et al., 2022; Wang et al., 2013).

However, despite the clear advantages demonstrated in these application areas, existing research often suffers from inadequate integration of technology. Most studies focus on low-altitude technology's application in single-use cases, such as traffic monitoring or pollution surveillance, while largely neglecting how these technologies can be integrated with other urban management systems, such as intelligent transportation systems (ITS) and urban safety networks (Boes et al., 2016; Li et al., 2017; Floreano & Wood, 2015). This lack of integration limits the overall effectiveness of low-altitude technology and prevents it from reaching its full potential in addressing the multifaceted needs of modern smart cities.

In the context of smart tourism cities, the application of low-altitude technology remains underex-

plored. While existing literature acknowledges the role of low-altitude technology in various urban sectors, it has given limited attention to its integration into tourism management systems. Smart tourism cities require more than just efficient traffic and environmental management; they also need enhanced tourist experiences and smarter service delivery. Low-altitude technology can play a crucial role in real-time tourist flow monitoring, panoramic sightseeing experiences, and emergency response services. However, most studies focus on the application of UAVs in isolated tourism settings, such as monitoring visitor flows in specific tourist spots or offering aerial tours. These studies fail to explore how low-altitude technology can contribute to broader resource optimisation, visitor management, and emergency services within a smart tourism city (Baggio et al., 2020). There is a significant gap in the research regarding how low-altitude technology can integrate with the overall tourism management system to optimise resource allocation, enhance emergency response capabilities, and improve overall visitor satisfaction.

The methodological approaches in existing research further exacerbate these gaps. Most studies rely heavily on case studies and qualitative analysis, which provide valuable insights into specific applications but lack the capacity for comprehensive, generalised assessments of technology effectiveness across different urban environments (Suanpang et al., 2022). Although case studies are useful for providing detailed accounts of low-altitude technology applications in particular cities or scenarios, they often fail to offer scalable conclusions that can be applied across multiple urban settings. Furthermore, qualitative analyses, such as expert interviews or surveys, often lack empirical data to substantiate the actual effectiveness of these technologies in large-scale applications. These studies typically highlight the potential benefits of low-altitude technology but fail to provide systematic evaluations of its real-world impacts, particularly in terms of cost-effectiveness, scalability, and social acceptance (Ilkhanizadeh et al., 2020).

The empirical research conducted to date has primarily focused on validating the technological feasibility of low-altitude technology in specific urban services, such as traffic management and environmental monitoring. However, these studies often lack cross-functional assessments of how low-altitude technology can interact with other systems across smart cities (Jiang et al., 2025). Most studies focus on the effectiveness of low-altitude technology in isolated domains without investigating how it could be integrated with other urban systems like intelligent traffic management, public safety networks, or urban resource management (Důbravová et al., 2024). This limitation makes it difficult to assess the full impact of low-altitude technology across smart city infrastructures.

Moreover, the current empirical studies tend to concentrate on single-use applications without exploring the holistic integration of low-altitude technology across urban sectors. For example, UAVs have been shown to improve monitoring in specific tourism areas, such as tracking visitor numbers at tourist spots, but there has been limited research on how low-altitude technology can work in synergy with other smart tourism management systems to create a seamless tourist experience (Mohamed et al., 2020). The lack of systematic empirical data on low-altitude technology's impact on overall tourism resource management and optimisation further limits our understanding of its true value in smart tourism cities (Madden et al., 2022).

While some research has contributed insights into the practical applications of low-altitude technology, there is a distinct lack of quantitative evaluations and scalability assessments. Most studies rely on case studies or qualitative analyses, which, while offering valuable contextual information, fail to provide comprehensive data on the long-term sustainability, cost-effectiveness, and social impact of UAVs in smart city applications (He et al., 2022). Additionally, limited exploration exists of how policy and regulatory challenges may influence the widespread adoption of low-altitude technology, which is essential for understanding the real-world barriers to its implementation.

1.4. Research gaps

Two key research gaps were identified in the current literature on the application of low-altitude technology in smart tourism cities. First, empirical analysis of low-altitude technology is lacking. Many studies focus on the technical feasibility of low-altitude technology in isolated domains or specific applications but lack comprehensive empirical research on its effects in smart tourism cities, especially in areas like resource optimisation and tourism management. While some studies have explored the potential of low-altitude technology in tourist flow monitoring and panoramic sightseeing, these studies often focus on specific scenarios or projects and do not systematically analyse how low-altitude technology can function in multiple contexts and scenarios within smart tourism cities. Therefore, this research will fill this gap by providing an empirical analysis of

the real-world application of low-altitude technology in Guangzhou, focusing on its effectiveness in improving resource management, optimising visitor experiences, and enhancing emergency response.

The second research gap is the integration of low-altitude technology with other urban management systems. While existing research has explored low-altitude technology in areas like traffic and environmental monitoring, few studies have systematically examined how low-altitude technology can collaborate with other management systems in smart tourism cities, such as intelligent transportation, public safety, and tourism resource management. Existing studies tend to focus on the independent application of low-altitude technology without delving into the synergistic effects between different technologies, which limits the overall impact of low-altitude technology. This study will address this gap by proposing a framework for integrating low-altitude technology with other systems in Guangzhou's smart tourism city. It will also analyse the effectiveness of cross-technology collaboration using empirical data, filling this important gap in the literature.

By focusing on the case of Guangzhou's smart tourism city, this study aims to address both of these research gaps. First, it will provide a comprehensive empirical assessment of the impact of low-altitude technology on resource management, visitor experience, and emergency management in Guangzhou's smart tourism city. Second, the study will explore how low-altitude technology can be effectively integrated with other smart city management systems in Guangzhou, offering a cross-technology integration model that is supported by empirical data. This research will provide new theoretical insights and practical guidance for the broader application of low-altitude technology in smart tourism cities.

2. Research methods

2.1. Study location

This study's research object is Guangzhou, a representative city known for its thriving tourism industry and leading smart city development. Guangzhou is one of China's key tourist destinations, boasting diverse cultural and natural resources, such as the Canton Tower, the Pearl River, and numerous historical sites, attracting millions of tourists annually. However, the rapid growth of the tourism industry has introduced challenges in managing tourist flows, optimising service quality, and ensuring sustainable development.

In recent years, Guangzhou has made significant progress in building smart city infrastructure and introducing innovative solutions to urban governance, including smart tourism. Guangzhou's tourism development strategy emphasises digital transformation, integrating technologies such as big data, IoT, and AI to upgrade tourism management and service delivery (Liu et al., 2023). However, current smart tourism practices in Guangzhou face limitations in real-time data collection, dynamic resource allocation, and immersive tourist experiences. These challenges highlight the necessity of introducing advanced technologies like low-altitude drones to further enhance the city's smart tourism model.

2.2. Selection of the research methods

In selecting the research methods for this study, several considerations were made to ensure that the analysis would provide a comprehensive and accurate understanding of the potential integration of low-altitude technology into Guangzhou's smart tourism framework. The primary rationale behind the choice of methods is to address both the technical feasibility and the broader socio-economic impacts of drone technology within the specific context of Guangzhou.

First, the textual analysis of policy documents was chosen because it offers a clear understanding of the existing policy support and institutional framework surrounding the integration of low-altitude technology. By focusing on key policy documents, such as the Smart City Development Plan and the Five-Year Tourism Development Plan, this study can identify potential gaps in current policy and suggest areas for improvement. This method is essential for providing insight into how well low-altitude technology aligns with the city's long-term development goals.

Second, quantitative methods, such as technical feasibility analysis, economic benefit analysis, and social impact analysis, were chosen to provide a data-driven approach to assess the actual performance and impact of low-altitude technology. These methods allow the study to evaluate the technical capabilities of drone systems and quantify their potential economic contribution and social acceptance. This multi-dimensional approach ensures that the study goes beyond theoretical assumptions and provides a well-rounded, evidence-based analysis.

The combination of qualitative policy analysis and quantitative evaluation allows for a holistic

understanding of the challenges and opportunities in integrating low-altitude technology into Guangzhou's smart tourism initiatives. By using these methods in tandem, the study can provide actionable recommendations grounded in the technical feasibility and the broader institutional and societal context.

2.3. Textual analysis based on policy texts

This study conducts a quantitative analysis of relevant policy texts to understand the policy support and institutional environment for integrating low-altitude technology into Guangzhou's tourism sector. This approach identifies the priorities and potential gaps within the existing policy framework to assess the feasibility of integrating drone technology with smart tourism development. The analysis includes the following steps:

1. Data collection

Collect key policy documents related to smart tourism, low-altitude technology, and smart-city development from national, provincial, and municipal levels, including Guangzhou's Smart City Development Plan and 14th Five-Year Tourism Development Plan.

2. Content analysis

Apply text-mining techniques to extract keywords and themes related to smart tourism, low-altitude technology, and tourism management. Quantitative metrics, such as term frequency and co-occurrence analysis, are used to identify key policy focuses and the relationships between drone technology and tourism development.

3. Gap analysis

Compare Guangzhou's current policy environment with international best practices to identify gaps in policy support and areas for improvement. This helps determine how to better facilitate the integration of low-altitude technology into tourism management.

2.4. Quantitative analysis methods

To systematically evaluate the potential of low-altitude technology in Guangzhou's smart tourism development, this study adopts the following three quantitative analysis methods:

1. Technical feasibility analysis

Objective — to evaluate the technical readiness and feasibility of low-altitude technology applications in Guangzhou's tourism sector.

Data source — technical reports, case studies from pilot projects in Guangzhou, and performance specifications of drone systems.

Methodology — analysis of navigation accuracy, battery endurance, payload capacity, and adaptability in complex urban environments; a comparative analysis of expected versus actual performance benchmarks conducted to identify gaps and improvement areas.

2. Economic benefit analysis

Objective — to quantify the economic impact of low-altitude technology in Guangzhou's tourism industry.

Data source — financial data from pilot projects, market analysis reports, and Guangzhou's tourism revenue statistics.

Methodology — constructing a cost-benefit model to evaluate equipment costs, operational expenses, and direct (e.g., ticket revenue) and indirect (e.g., tourist spending, city branding) economic contributions. ROI calculations are performed to determine the financial feasibility of integrating drone technology.

3. Social impact analysis

Objective — to analyse public acceptance and behavioural patterns related to drone-based tourism services.

Data source — social media platforms, online travel reviews, and tourist flow data from Guangzhou.

Methodology — natural language processing (NLP), which is used to conduct sentiment analysis of public feedback regarding drone-assisted services, categorising responses into positive, neutral, and negative sentiments. Behavioural data, such as participation rates in drone sightseeing projects, is analysed to assess user preferences and levels of acceptance.

2.5. Research process

The research process includes the following steps:

1. Policy and context analysis — conducting a detailed review of Guangzhou's tourism development needs and smart city planning, examining the relationship between policy support and technology applications.

2. Data collection — gathering technical, economic, and social data from pilot projects, government reports, and big data platforms.

3. Quantitative evaluation — using the above methods to systematically analyse the technical feasibility, economic impact, and social effects of integrating low-altitude technology into smart tourism.

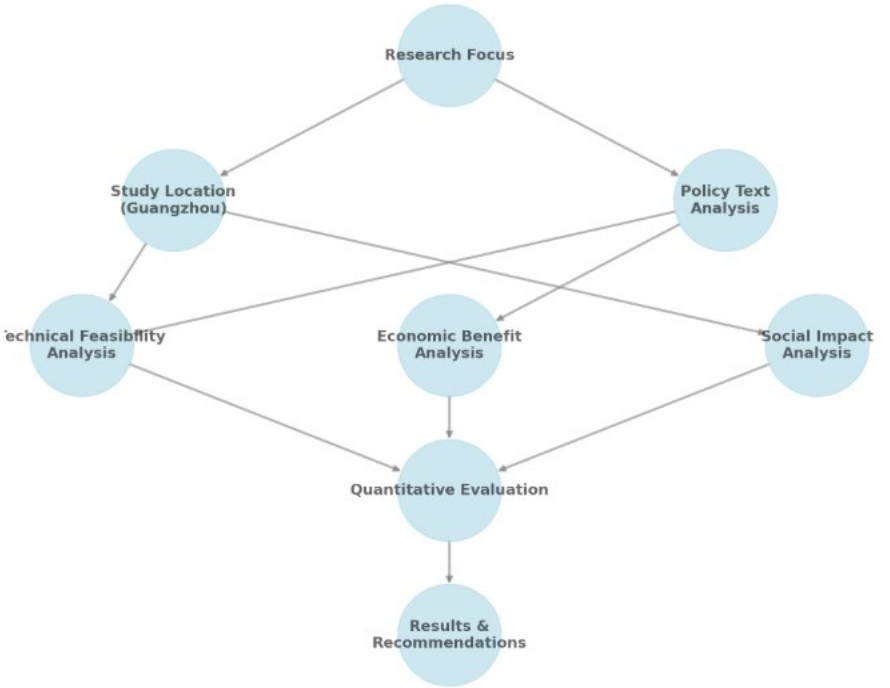

Fig. 1. Research framework

4. Results and recommendations — synthesise the findings to propose actionable recommendations for optimising Guangzhou's smart tourism model using low-altitude technology.

Fig. 1 shows the flow chart of this study's methodology. This integrated research approach ensures that the analysis is rooted in Guangzhou's specific needs, providing a comprehensive understanding of the potential for integrating low-altitude technology with smart tourism. The inclusion of policy analysis adds depth to the institutional context, supporting a well-rounded evaluation.

3. Research results and analysis

The data collection for this study was conducted primarily during October and November 2024, covering the necessary data for policy text analysis, technical feasibility analysis, economic benefit analysis, and social impact analysis. The data was sourced from policy documents published by the Guangzhou government, technical reports, market analysis, and social media and tourist flow data, ensuring the timeliness and reliability of the research results.

3.1. Results of policy text analysis

This study conducted a textual analysis of 57 policy documents related to smart tourism, low-altitude technology, and urban development in Guangzhou. These policy documents cover the period from 2010 to 2023, a timeframe chosen because 2010 marked the beginning of systematic planning for smart city construction in China, while low-altitude technology (e.g., drones) began expanding from military and research applications to civilian and commercial use during this period. This time range comprehensively captures the evolution of Guangzhou's policy initiatives in integrating smart tourism with low-altitude technology.

The analysed documents were sourced from the following channels: official Guangzhou government websites, policy announcement platforms, municipal planning reports, legislative documents, and research publications related to smart cities and low-altitude technology. These sources ensure the authority and comprehensiveness of the policy data. By applying text mining techniques, this study extracted key terms and themes from the policy texts, followed by frequency analysis, co-occurrence analysis, and gap analysis. The findings reveal key trends, policy gaps,

and development priorities in Guangzhou's policy framework. This analysis provides empirical evidence and data-based recommendations to further refine the policy structure and promote the application of low-altitude technology in the field of smart tourism.

The frequency analysis of policy keywords, as shown in Fig. 2, highlights the areas of emphasis on Guangzhou's policy framework on smart tourism and low-altitude technology. The most frequently mentioned keyword is "Smart Tourism" (50 occurrences), indicating its prominence in Guangzhou's strategic development agenda. "Tourism Experience" (40 occurrences) and "Low-Altitude Technology" (35 occurrences) follow closely, suggesting a strong focus on improving visitor satisfaction and leveraging emerging technologies like drones.

However, keywords like "Safety Standards" (15 occurrences) and "Data Sharing" (25 occurrences) appear less frequently, reflecting potential gaps in the current policy framework. These aspects are crucial for ensuring the safe and efficient integration of low-altitude technology into tourism operations. For example, insufficient emphasis on safety standards could delay drone deployment in crowded urban areas, while limited data-sharing mechanisms may hinder cross-departmental coordination in implementing drone-based services.

Fig. 3 presents the co-occurrence matrix of policy keywords, demonstrating the interrelationships between key terms. The strongest co-occurrence is observed between "Smart Tourism" and "Tourism Experience" (0.9), underscoring the close linkage

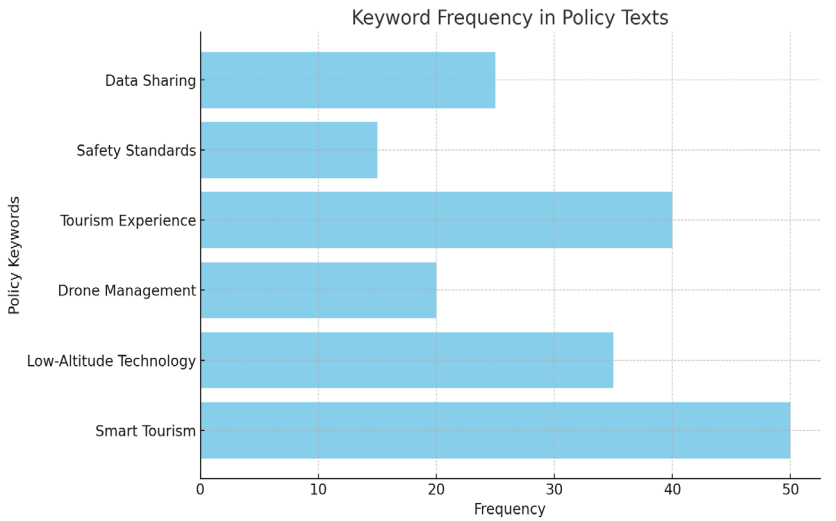

Fig. 2. Keyword frequency in policy texts

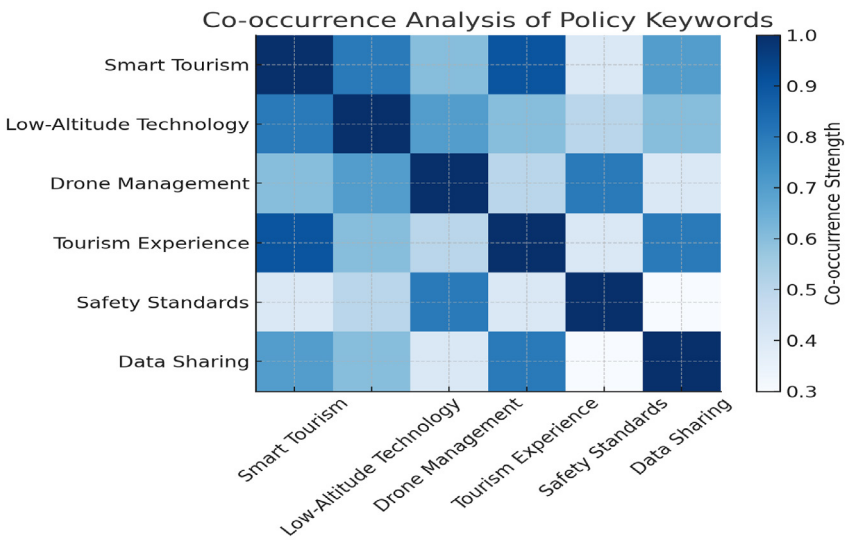

Fig. 3. Co-occurrence analysis of policy keywords

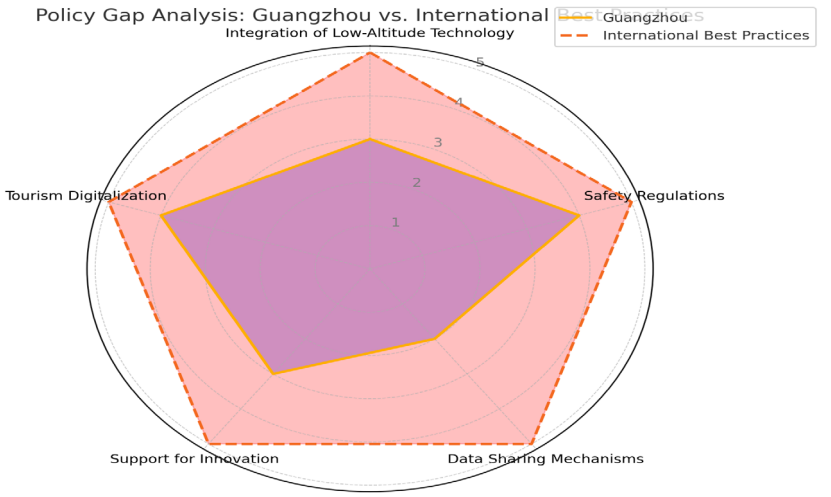

Fig. 4. Policy gap analysis

between enhancing visitor satisfaction and the adoption of smart technologies. This suggests that policy efforts are heavily focused on improving the overall tourist experience through digital transformation initiatives.

"Low-Altitude Technology" exhibits moderate co-occurrences with "Drone Management" (0.7) and "Data Sharing" (0.6), reflecting a growing policy interest in operational and technical aspects of drone deployment. However, weaker correlations are noted between "Safety Standards" and other keywords (e.g., 0.4 with "Smart Tourism" and "Data Sharing"), indicating a fragmented approach to regulatory oversight. This lack of integration could result in operational inefficiencies or public resistance to drone applications.

The radar chart in Fig. 4 compares Guangzhou's policy environment with international best practices across five key aspects. While Guangzhou demonstrates relatively strong support for "Tourism Digitalization" (4/5) and "Safety Regulations" (4/5), significant gaps remain in "Integration of Low-Altitude Technology" (3/5) and "Data Sharing Mechanisms" (2/5). For example, international benchmarks emphasise well-established frameworks for sharing operational data across agencies, ensuring seamless integration of low-altitude technology into urban tourism management. Guangzhou's lower scores in these areas highlight the need for targeted improvements to enhance its institutional support and technological readiness for low-altitude drone applications.

The analysis results indicate that Guangzhou's policy framework places significant emphasis on smart tourism and improving visitor experiences, showing notable strengths in tourism digitalisation and basic safety regulations. However, there are clear policy gaps in areas such as data-sharing mechanisms and innovation support, where Guangzhou lags behind international best practices. Additionally, the integration of low-altitude technology and safety regulation remains fragmented, lacking a systematic and cohesive framework. Overall, while Guangzhou's policy foundation is solid, further improvements in data collaboration and innovation-driven policies are essential to fully leverage the potential of low-altitude technology in smart tourism.

3.2. Quantitative analysis results

The data for the technical feasibility analysis (as shown in Fig. 5 and Table 1) are primarily sourced from technical reports on the application of low-altitude technology in Guangzhou, performance specifications of drone systems, and case studies from several pilot projects. These data points cover the key application areas of low-altitude technology in smart tourism scenarios. By comparing actual performance with industry-standard expectations, the analysis identifies gaps in technical maturity and application potential. Eight critical performance metrics, including navigation accuracy, battery endurance, payload capacity, and stability in complex environments, were selected to provide a comprehensive technical diag-

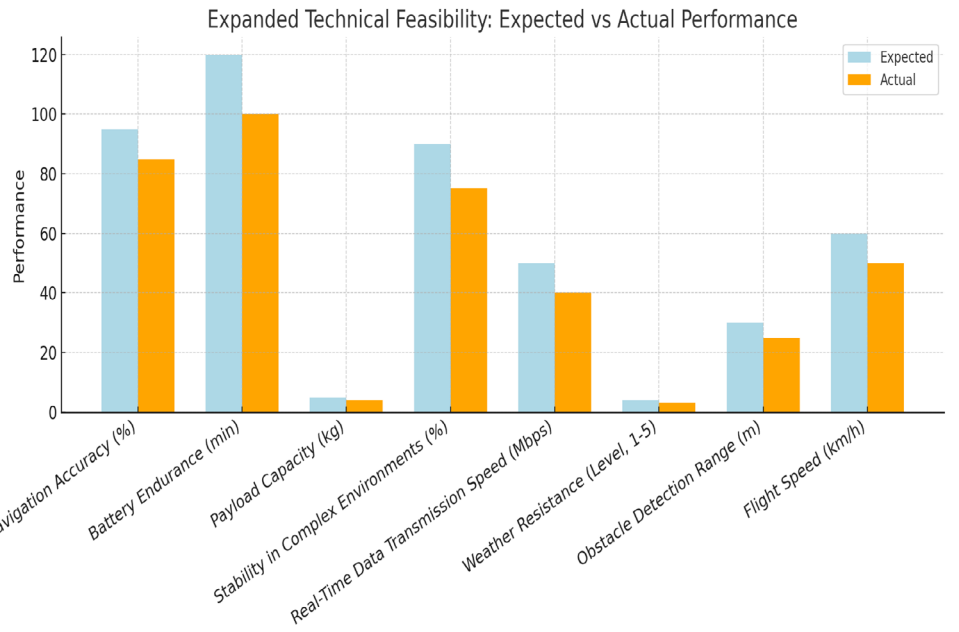

Fig. 5. Expanded technical feasibility

Tab. 1. Performance metrics

Performance Metrics	Expected Value	Actual Value	Gap (%)
Navigation accuracy (%)	95	85	10
Battery endurance (min)	120	100	20
Payload capacity (kg)	5	4	20
Stability in complex environments (%)	90	75	15
Real-time data transmission speed (Mbps)	50	40	20
Weather resistance (Level, 1–5)	4	3	25
Obstacle detection range (m)	30	25	16.7
Flight speed (km/h)	60	50	16.7

nosis. The aim is to pinpoint current shortcomings, offer actionable recommendations for improvement, and provide robust data support for integrating low-altitude technology into Guangzhou's smart tourism framework.

Fig. 5 and Table 1 reveal that low-altitude technology in Guangzhou's tourism sector demonstrates performance gaps across multiple key metrics compared to expected standards. First, in terms of navigation accuracy and stability in complex environments, the actual navigation accuracy of drones reaches 85 %, which is relatively close to the expected 95 %. However, stability in urban environments performs at only 75 %, falling short of the 90 % target. This indicates the need for enhanced anti-interference capabilities to ensure reliable operations in densely populated areas with complex signals. Additionally, optimising navigation accuracy is essential for delivering precise services across diverse urban scenarios.

Second, significant gaps are observed in battery endurance and payload capacity. The actual battery endurance is 100 minutes, 20 % lower than the expected 120 minutes, while payload capacity stands at 4 kg, also 20 % below the expected 5 kg. These shortcomings limit the ability of drones to undertake longer operations and carry heavier equipment or materials. Furthermore, the real-time data transmission speed of 40 Mbps falls 20 % short of the expected 50 Mbps, potentially affecting the drones' ability to process real-time data effectively, thereby reducing responsiveness and operational efficiency in dynamic scenarios. These gaps underscore the urgent need for advancements in battery technology and communication systems to support more complex and diverse tasks.

Finally, the data shows deficiencies in weather resistance and obstacle detection range, which are crucial for environmental adaptability. The weather resistance is rated at Level 3 (on a scale of 1–5), below the expected Level 4, limiting drone deployment under adverse weather conditions. The obstacle detection range is 25 meters, 16.7 % less than the expected 30 meters, reflecting reduced effectiveness in crowded urban environments. Additionally, the flight speed is 50 km/h, below the expected 60 km/h, indicating inefficiencies in covering larger areas. Collectively, these metrics highlight the need for improvements in battery performance, environmental adaptability, and real-time communication capabilities. This analysis provides a clear roadmap for optimising low-altitude technology and ensuring its effective integration into Guangzhou's smart tourism framework.

The economic benefit analysis in this study is based on actual statistical data for Guangzhou's low-altitude technology applications in smart tourism from 2020 to 2024, combined with market trend projections and growth models for 2025 to 2029. The actual data was sourced from official Guangzhou government tourism statistics, operational reports from low-altitude technology companies, and publicly available policy documents and academic research. The future five-year projections are calculated using the Compound Annual Growth Rate (CAGR) formula, considering technological advancements, policy support, and market demand. The CAGR formula is as follows:

$$\text{CAGR} = \frac{\text{Final Value}}{\text{Initial Value}}^{\frac{1}{\text{Number of Years}}} - 1$$

With an observed growth rate of 25 %, the projections were benchmarked against historical growth trends of similar technologies in the industry. The data analysis shows that the economic output of low-altitude technology in 2020 was approximately USD 1 million, growing to USD 10 million by 2024, reflecting rapid development in this field. By 2029, its economic benefits are expected to surpass USD 200 million, demonstrating the critical role and vast growth potential of drone technology in smart tourism cities.

Between 2020 and 2024, the economic output of Guangzhou's low-altitude technology experienced rapid growth, increasing from an initial USD 1 million to USD 10 million. This growth was driven by the widespread application of drones in smart tourism services in Guangzhou, including real-time tourist flow monitoring, aerial promotional imagery for urban attractions, and enhanced emergency response and resource management. In 2020, low-altitude technology was primarily in its pilot stage, with limited service coverage. However, as the development of smart cities accelerated and drone technologies matured, their integration into urban tourism management expanded steadily. By 2023 and 2024, drones contributed significantly to Guangzhou's international tourism branding by providing high-quality aerial imagery and improving visitor experiences, which directly boosted related economic benefits. Meanwhile, policy initiatives supporting smart tourism created a favourable environment for this technological growth.

From 2025 to 2029, economic benefits are expected to grow exponentially, reaching USD 25 million by 2025 and surpassing USD 200 million by 2029. This projection is based on several factors, including technological advancements, policy support, and expanding market demand. First, drone applications in Guangzhou's smart tourism sector are expected to deepen, covering more scenic spots and introducing intelligent panoramic tours and drone-guided services, further increasing tourist spending and tourism revenue. Second, policy support will continue to play a critical role; with the improvement of cross-departmental data-sharing mechanisms and operational standardisation, the large-scale application of drones will significantly improve efficiency. Additionally, declining costs of low-altitude technology, increasing market demand, and continuous upgrades in smart hardware and software will provide the foundation for rapid growth in economic benefits.

Despite the promising projections, several challenges must be addressed to realise the anticipated economic growth. Currently, Guangzhou faces deficiencies in operational standardisation and policy support for low-altitude technology, such as limited coordination in safety regulations and data-sharing mechanisms, which may hinder the full deployment of drones. On the technical side, further optimisation is required, particularly in such areas as drone battery endurance and environmental adaptability, to handle complex urban environments and adverse weather conditions. Moreover, efficient data transmission capabilities are essential to achieving real-time monitoring and dynamic response. To address these challenges, Guangzhou must increase investment in R&D, promote technological innovation, and collaborate with enterprises and research institutions. At the same time, policy reforms, such as improving regula-

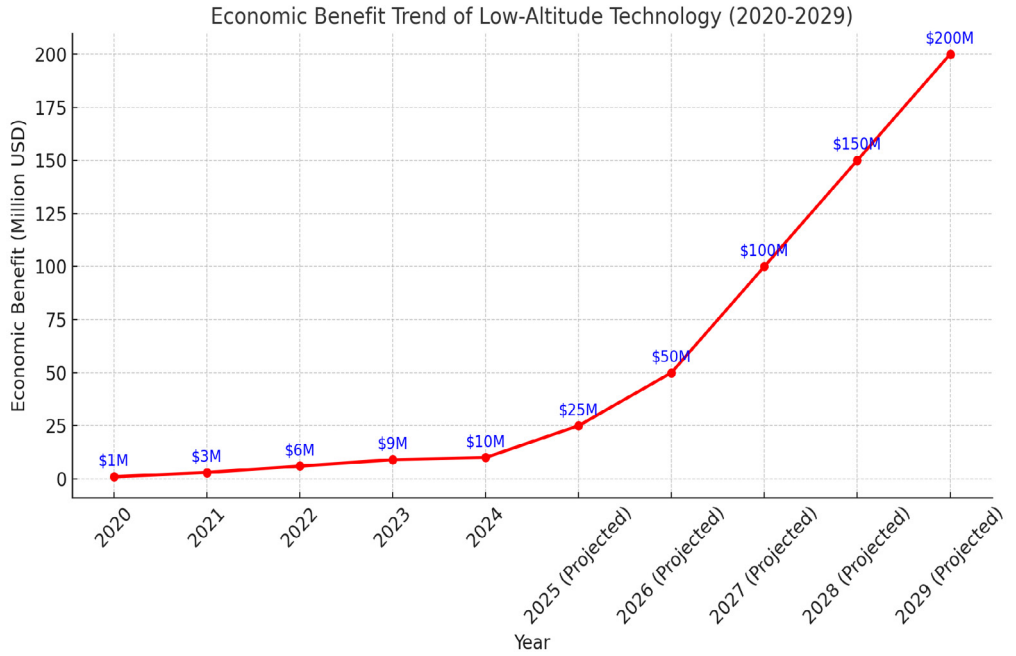

Fig. 6. Economic benefit trend of low-altitude technology (2020–2029)

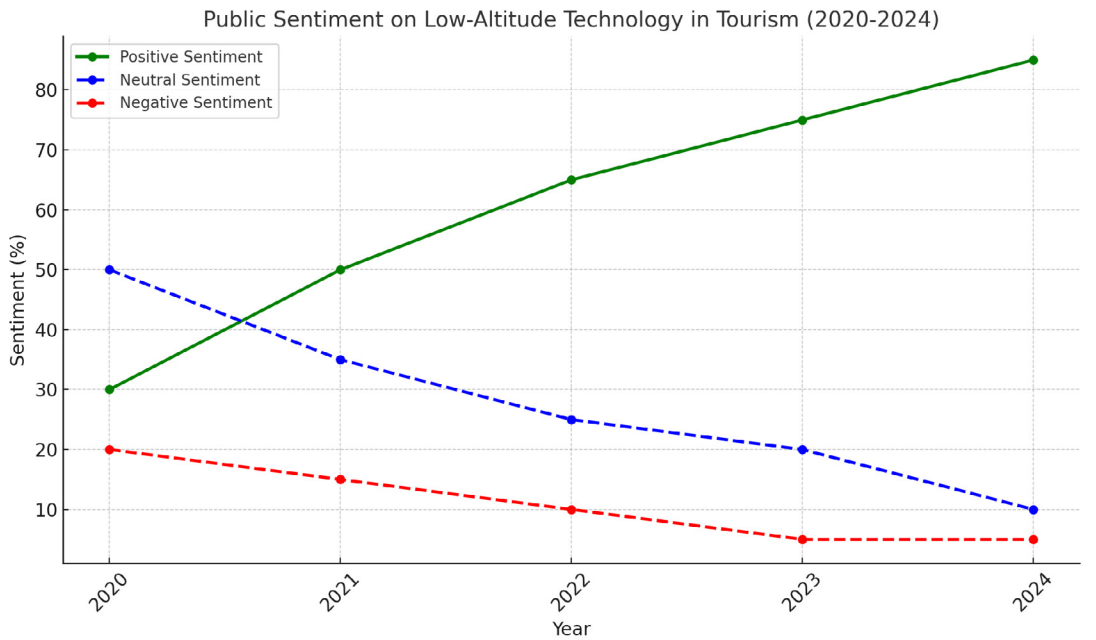

Fig. 7. Public sentiment on low-altitude technology in tourism (2020–2024)

tory frameworks and fostering cross-departmental cooperation, will be critical for realising the projected economic benefits.

The social impact of low-altitude technology on Guangzhou's smart tourism sector has been evaluated through public sentiment analysis and public engagement trends from 2020 to 2024. The analysis utilises big data derived from social media platforms, online travel reviews, and participation rates in drone-enabled tourism projects. The findings are illustrated through two key metrics: sentiment trends and public participation growth.

From the sentiment analysis, as shown in Fig. 7, public perception of drone technology in tourism has shown significant improvement over the past five years. Positive sentiment increased from 30 % in 2020

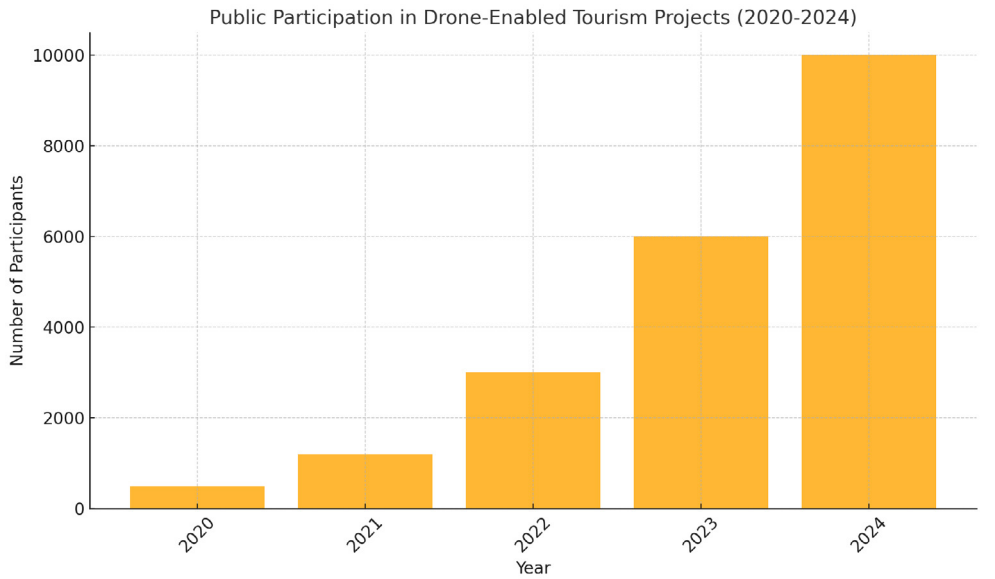

Fig. 8. Public sentiment regarding low-altitude technology in tourism (2020–2024)

to 85 % in 2024, reflecting growing acceptance and enthusiasm for drone-based applications in tourism. Initially, public scepticism was driven by concerns about privacy, safety, and noise pollution, as evidenced by the 20 % negative sentiment in 2020. However, sustained efforts in addressing safety standards and improving operational transparency, combined with the enhanced user experience offered by drone services, have drastically reduced negative sentiment to 5 % by 2024. Meanwhile, neutral feedback has also declined from 50 % in 2020 to 10 % in 2024 as more users shifted their perceptions toward a positive stance.

Public participation in drone-enabled tourism projects has grown exponentially, as shown in Fig. 8. The number of participants increased from 500 in 2020 to 10,000 in 2024, demonstrating widespread public interest in immersive drone-assisted tourism services, such as panoramic drone tours, real-time virtual guided tours, and interactive aerial displays. This growth can be attributed to the increasing integration of drone applications in iconic tourist attractions, such as the Canton Tower and Pearl River Night Cruise. Drone-assisted virtual experiences have also gained popularity among tech-savvy tourists, enhancing the diversity and accessibility of tourism services.

The interplay between improving public sentiment and increasing participation highlights the successful integration of low-altitude technology into Guangzhou's tourism sector. However, the findings also underscore the importance of sustained efforts in addressing social concerns related to privacy and regulatory oversight. As Guangzhou continues to expand its drone applications in tourism, efforts to engage the public through education campaigns and transparent communication about safety and privacy measures will be critical to maintaining positive perceptions.

In a nutshell, the social impact analysis demonstrates that low-altitude technology has been well-received by the public and has driven substantial engagement in smart tourism initiatives. The combined rise in positive sentiment and participation highlights the potential of drones to enhance tourism experiences and strengthen public trust in innovative technologies. Moving forward, addressing residual social concerns and fostering inclusive participation will be pivotal to maximising the social benefits of low-altitude technology in smart tourism.

4. Discussion

The integration of low-altitude technology into Guangzhou's smart tourism framework represents a significant advancement in urban tourism management and service innovation. The findings of this study reveal that low-altitude technology, primarily through drones, has become an indispensable tool for enhancing visitor experiences, optimising resource management, and addressing complex urban tourism challenges. By analysing its economic, social, and technical impacts, this research builds upon prior studies, such as Důbravová et al. (2024), which emphasise the transformative potential of digital

technologies in shaping smarter and more sustainable tourism systems. However, while the economic growth trajectory and social acceptance of drones in Guangzhou have been remarkable, several underlying challenges demand attention to fully realise their long-term potential.

Economically, the exponential growth from USD 1 million in 2020 to USD 10 million in 2024 reflects the increasing integration of drones into various aspects of urban tourism, ranging from real-time monitoring to aerial tourism branding. This aligns with observations by Hossein Motlagh et al. (2016) that low-altitude technology's economic impact grows with diversification into new service areas. Yet, the technical constraints identified in this study, such as limitations in battery endurance, payload capacity, and operational stability in complex urban environments, remain significant barriers to scaling these services. Moreover, the projected economic benefits of over USD 200 million by 2029 depend on stakeholders' ability to address these challenges through targeted investments in R&D and the development of standardised operational frameworks. Therefore, while the financial prospects are promising, the success of future applications will rely heavily on advancing core drone technologies and fostering public-private collaborations to drive both innovation and market adoption.

The social impact analysis highlights a critical shift in public attitudes toward low-altitude technology. Building on findings by Wang et al. (2023), which underline the importance of public trust in urban drone applications, this study demonstrates that positive sentiment toward drones in tourism grew from 30 % in 2020 to 85 % in 2024. This growth reflects not only the improved user experience provided by drones but also the effectiveness of safety and transparency measures implemented in Guangzhou's urban management. However, residual concerns about privacy and safety remain a challenge, as indicated by lingering negative sentiments, albeit at a reduced level. These findings suggest that stakeholders must prioritise transparent communication about operational protocols and further engage the public through education campaigns. Demonstrating the tangible benefits of drone-enabled services, such as improved emergency response and sustainable tourism practices, will be crucial to fostering long-term public acceptance.

From a governance and policy perspective, the findings also echo Shafiee et al. (2019), who argue that the success of smart tourism initiatives depends on the integration of diverse technologies into a cohesive urban system. Although Guangzhou has made commendable progress in leveraging low-altitude technology, this study reveals gaps in data-sharing mechanisms and cross-departmental collaboration. For instance, while drones have proven effective in monitoring tourist flows and providing immersive experiences, the lack of a unified framework for coordinating data across municipal departments hinders their full potential. Stakeholders must, therefore, focus on developing standardised protocols for data integration and governance. Learning from international best practices, such as Amsterdam's robust urban technology frameworks, could provide valuable insights for Guangzhou in creating seamless interoperability between low-altitude technology and other smart city systems.

Several strategic recommendations emerge to address these challenges. First, investing in technological advancements remains a priority. Enhancements in drone hardware, such as extended battery life and improved weather resistance, combined with advancements in AI-based navigation and real-time data processing, will enable drones to operate more effectively in complex urban environments. Such investments should be supported by public funding and incentivised private-sector partnerships, as suggested by Giones and Brem (2017), who emphasise the role of collaborative ecosystems in driving innovation in emerging technologies.

Second, regulatory frameworks must evolve to keep pace with technological advancements and market expansion. This includes updating safety standards, streamlining licensing processes, and establishing clear guidelines for data privacy and security. The development of drone-specific urban airspace policies akin to those implemented in Shenzhen could serve as a model for Guangzhou to ensure safe and efficient drone operations in densely populated areas.

Finally, engaging key stakeholders, including tourists, local communities, and businesses, is essential for sustaining the momentum of drone adoption in smart tourism. As Muhmad Kamarulzaman et al. (2023) highlight, fostering stakeholder collaboration is critical to overcoming implementation barriers and ensuring equitable benefits from new technologies. In Guangzhou's case, creating participatory platforms where stakeholders can provide feedback, share concerns, and contribute to policy development would enhance both public trust and operational efficiency.

The proposed Low-Altitude Technology-Based Smart Tourism Service Model (Fig. 9) for Guangzhou

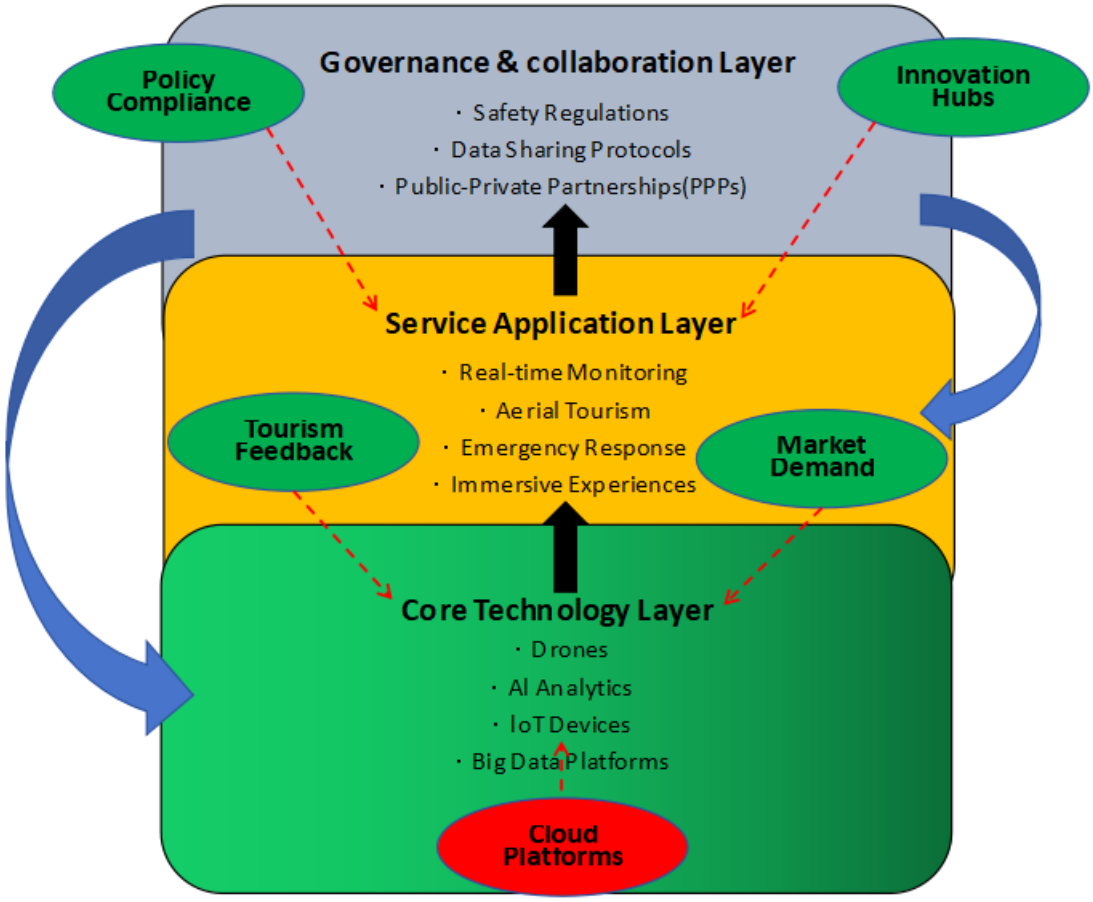

Fig. 9. Low-altitude Technology-based Smart Tourism City Service Model

integrates three interconnected core layers: Core Technology, Service Application, and Governance and Collaboration, creating a cohesive and efficient system that addresses critical technological, operational, and governance elements. At its foundation, the Core Technology Layer serves as the backbone, incorporating drones, AI algorithms, IoT devices, and big data platforms to enable real-time data collection, processing, and actionable insights. These technologies support operational efficiency and enhance tourist services, such as real-time monitoring of tourist flows, panoramic sightseeing, and emergency responses. Building on this infrastructure, the Service Application Layer operationalises these capabilities to deliver diverse tourism services, including live crowd monitoring, immersive aerial tourism experiences, emergency response capabilities, and virtual or augmented reality tours, improving both visitor satisfaction and city-level management. The Governance and Collaboration Layer ensures the system operates within a robust regulatory framework, addressing safety, data sharing, and stakeholder coordination through safety regulations, data integration protocols, and public-private partnerships. These layers are interconnected through seamless communication and workflows, with data from the Core Technology Layer directly feeding into the Service Application Layer, while the Governance Layer ensures security and collaboration. This model provides a strategic, scalable framework for integrating low-altitude technology into Guangzhou's smart tourism ecosystem, offering policymakers, businesses, and researchers a guide to align technological advancements with practical applications and governance structures to enhance urban tourism sustainability and efficiency.

The integration of low-altitude technology into Guangzhou's smart tourism sector represents a promising frontier for innovation and growth. While the economic and social benefits are evident, addressing technical constraints, regulatory gaps, and public concerns will be crucial to unlocking its full potential. By aligning technological advancements with stakeholder interests and adopting a collabora-

tive governance approach, Guangzhou can set a benchmark for other cities seeking to leverage drones for smarter, more sustainable urban tourism systems. This study contributes to the growing body of knowledge on the application of low-altitude technology in smart tourism cities and provides actionable insights for policymakers, industry leaders, and researchers aiming to drive the next wave of urban innovation.

Recent studies have emphasised the transformative potential of low-altitude technology in urban tourism management, particularly in optimising operational efficiency and enhancing visitor experiences. For example, Sevilla-Sevilla et al. (2024) highlighted how drones are increasingly being utilised for real-time crowd monitoring and emergency response, aligning with this study's findings on the critical role of low-altitude technology in improving tourism safety and resource management. However, while previous research primarily focuses on individual case studies, this study extends the discussion by providing a comprehensive evaluation framework that integrates technical feasibility, economic viability, and social impact. This multi-dimensional approach ensures that the deployment of drones is not only technologically feasible but also economically sustainable and socially acceptable. Furthermore, the research introduced in this article supports the conclusions of Madden et al. (2022), who argue that while drones contribute to tourism enhancement, their large-scale integration requires regulatory refinement and stronger public-private collaborations, both of which are identified as key priorities in Guangzhou's smart tourism strategy.

Moreover, the governance challenges associated with integrating drones into smart city frameworks have been widely discussed in recent literature. Studies such as Mohamed et al. (2023) emphasised the need for cross-sectoral coordination and robust data-sharing mechanisms to maximise the efficiency of drone-based tourism services. The findings of this study corroborate this perspective, as the policy gap analysis indicates that while Guangzhou has made strides in digitalising its tourism sector, significant deficiencies remain in regulatory frameworks, particularly regarding data integration and safety standards. By addressing these challenges through an improved governance model, as proposed in the Low-Altitude Technology-Based Smart Tourism Service Model (Fig. 9), Guangzhou can serve as a reference for other urban centres seeking to implement drone technology in tourism management. Furthermore, this study builds upon the work of Ayamga et al. (2021), who stressed that regulatory bottlenecks often hinder the scalability of drone applications. By proposing an integrated framework that aligns regulatory oversight with technological innovation, this study provides practical solutions for overcoming implementation barriers and ensuring the long-term sustainability of low-altitude tourism services.

Conclusions

This study proposed a comprehensive service model for integrating low-altitude technology into Guangzhou's smart tourism ecosystem, addressing the critical technological, operational, and governance elements needed for sustainable urban tourism development. The three-layered model, including the Core Technology Layer, the Service Application Layer, and the Governance and Collaboration Layer, illustrates how cutting-edge technologies, such as drones, AI, IoT devices, and big data platforms, can be systematically leveraged to enhance tourism services, improve operational efficiency, and ensure secure and collaborative management. By aligning technological advancements with practical applications and governance frameworks, the model provides a scalable and adaptable strategy for addressing the complexities of modern tourism cities.

The significance of this research lies in its interdisciplinary approach, combining low-altitude technology and smart tourism concepts to propose an innovative and actionable framework. From a theoretical perspective, it advances the understanding of how low-altitude technology can be integrated into urban tourism systems, enriching the academic discourse on smart tourism cities. Practically, the proposed service model offers policymakers, businesses, and researchers a structured guide for implementing low-altitude technology, enabling efficient resource management, improving visitor experiences, and fostering public-private collaboration. Furthermore, the model contributes to bridging the gap between technical feasibility and real-world applications by addressing the challenges of safety, regulatory oversight, and data sharing.

Despite its contributions, this study is not without limitations. First, the research primarily focuses on Guangzhou, which, while representative of rapidly urbanising cities, may limit the generalisability of the findings to other cities with differing tourism infrastructures, regulatory environments, or technological

capabilities. Second, the proposed model remains theoretical, and its practical implementation has not yet been empirically tested, leaving room for uncertainty regarding its scalability and adaptability in real-world scenarios. Lastly, the analysis of external influencing factors, such as social acceptance of drones and cost-benefit trade-offs, requires further empirical validation to understand their broader implications in diverse urban contexts.

Future research should focus on addressing these limitations to enhance the applicability and robustness of the proposed service model. First, empirical studies should be conducted to validate the model through pilot projects in Guangzhou and other cities with varying urban and tourism characteristics. This would provide valuable insights into the model's scalability and adaptability across different contexts. Second, further exploration of advanced technologies, such as drone swarms, 5G-enabled communication, and blockchain for data security, could refine the technological foundation of the Core Technology Layer. Third, interdisciplinary studies should examine the social and economic impacts of integrating low-altitude technology into smart tourism, particularly regarding public acceptance, privacy concerns, and cost-effectiveness. Finally, future research should explore collaborative frameworks between cities, fostering knowledge sharing and best practices to accelerate the global adoption of low-altitude technology in smart tourism ecosystems.

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