

Engineer 4.0 and Manager 4.0 Competencies in Polish Family Manufacturing Enterprises

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ABSTRACT

The study investigates the integration of Industry 4.0 concepts within Polish family manufacturing enterprises, focusing on the evolving competencies required of Engineer 4.0 and Manager 4.0. Utilizing a survey of 178 family businesses, the research explores correlations between organizational characteristics—such as size, ownership, and technological sophistication—and perceptions of Industry 4.0 competencies. Statistical analyses reveal significant relationships between these characteristics and the evaluation of strategic management, interdisciplinary collaboration, and technical skills. Despite the transformative potential of Industry 4.0 technologies, implementation challenges persist, highlighting the need for tailored competency models to bridge these gaps. The findings offer valuable insights into aligning managerial and engineering expertise with the dynamic demands of modern manufacturing environments.

KEYWORDS

Industry 4.0, engineer 4.0, manager 4.0, family businesses, family firms.

Introduction

Family businesses combine both family and business aspects, creating a unique organizational form that is distinguished by specific dynamics and management character (Siuta-Tokarska & Juchniewicz et al., 2023). At the same time, they are the largest source of private sector employment in the world, as highlighted by various studies, including Pini (2019). In addition to the key role they play in local and international economies, family businesses are gaining increasing attention from researchers. The growing interest in the impact of these companies on the global economy has been described in the work of Siuta-Tokarska, Juchniewicz, Kowalik, Thier, Gross-Gołacka (2023), and Mikoláš and Matejun (2023), among others. The authors of both publications point to the significant impact of family businesses on economic

development and their potential importance in the context of industrial transformation.

Interest in the topic of family businesses is reflected in the growing number of scientific articles published. Based on a review of the literature obtained from the Scopus database, a steady increase in the number of papers devoted to this topic can be observed until 2023 (Fig. 1). Conducting a bibliographic analysis using the filters presented in the research methodology allowed us to determine that the total number of publications on family businesses in the period analyzed was 5946. The dynamics of the growth of interest in this topic is clearly visible - the number of publications over the years has increased from 253 in the initial period to 719 in 2023. This trend indicates the growing popularity of research on family businesses, both in theoretical and practical contexts, which may indicate their key role in modern economic models.

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Management and Production Engineering Review

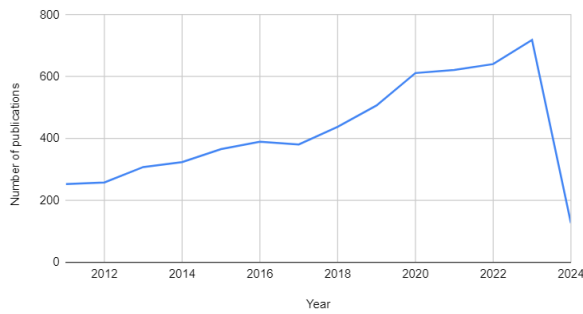


Fig. 1: The number of publications on family businesses in the years 2011-2024

The term Engineer 4.0 directly refers to the implementation of the Industry 4.0 concept in companies, which are characterized by digitization, automation and integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI) and robotics (Politanska, 2020). The competencies that Engineers 4.0 should possess include not only advanced technical knowledge, but also the ability to adapt to dynamically changing technological conditions. This means that an Engineer 4.0 should not only be a specialist in his or her field, but also open to innovation and ready to take on new challenges (Politanska, 2020; Gracel et al., 2017).

The literature review also examined interest in the issue of engineering competence in the context of Industry 4.0. Analysis of bibliometric data based on the Scopus database showed that the number of scientific publications on this issue totaled 344 articles, after applying certain restrictions on the selection of materials. The average number of articles published annually on this topic was 24, which shows the steady interest of researchers in this issue over the years.

The year 2020 was particularly significant, as a record number of 45 publications devoted to the competencies of Engineer 4.0 were recorded at that time. The growing interest in the topic continued in 2021-2023, as confirmed by data from the literature (Fig. 2). It can be assumed that this growth is a result of the increasing implementation of Industry 4.0 solutions, which require engineers to augment traditional skills with competencies related to modern technologies.

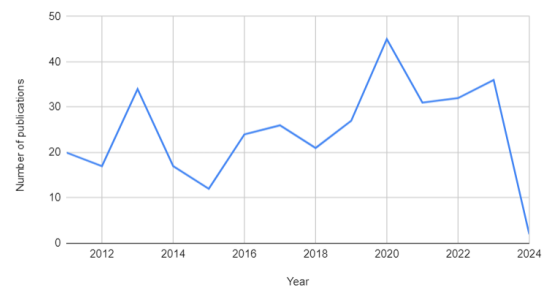


Fig. 2: The number of publications on engineering competencies in the years 2011-2024

The literature review performed on the basis of articles selected from the Scopus database aimed to assess the level of interest in the topics of family businesses and engineering competence in the context of Industry 4.0. To perform a precise analysis, a combination of relevant keywords was used, which allowed narrowing down the number of analyzed publications to those that address both topics. This methodology not only made it possible to identify publications focusing on family companies and engineering competencies but also made it possible to demonstrate the links between these topics in the identified articles.

The total number of articles after applying filters and analyzing titles, keywords, and abstracts was 11 publications. Of the selected articles, 10 were published between 2019 and 2023, indicating a relatively new but rapidly growing area of research. In particular, 2023 stands out as the year with the highest number of publications, confirming the trend of growing interest in this issue in the scientific literature (Fig. 3). This dynamic of publications may be due to the growing need to study family businesses in the context of modern technologies and the changes that are taking place in engineering competencies due to the implementation of Industry 4.0 solutions.

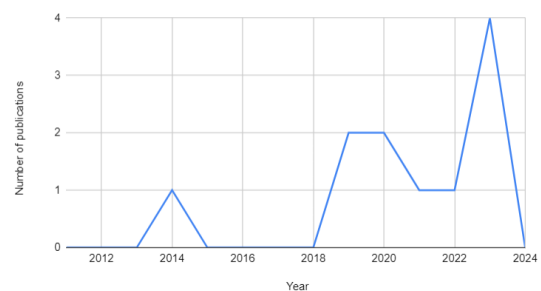


Fig. 3: The number of selected publications in the years 2011-2024

The articles selected for analysis by Więcek-Janka, Chocholowska, Gralinskaya, , and Zarówna (2024) were subjected to a detailed scientometric analysis to identify the main research themes in publications on family businesses and their functioning in the context of Industry 4.0. This analysis revealed the diversity of issues that the authors of these publications addressed, reflecting the complexity of family business management issues in the era of digitization and automation.

According to the study, the authors focused on several key research areas. First, much of the literature focused on running companies under the conditions of the fourth industrial revolution, as detailed by Kazancoglu, Sezer, Ozkan-Ozen, Mangla and Kumar (2021). They analyzed how technological changes affect the business models and daily operations of family businesses.

Another important area was the challenges of managing family businesses, as highlighted in their work by Panda, Gupta and Sethi (2020). This research focused on issues related to business succession, internal conflicts, and the need to adapt to dynamic market changes.

Studies of how family firms operate in the manufacturing sector have also been an integral aspect of the analyses. The work of Cuccullli, Dileo and Pini (2022) and Pini (2019) examined how family firms operate in the manufacturing industry, particularly in the context of globalization and increasing technological demands.

Papers on the international expansion of family businesses were also an important part of the literature. Petrů, Tomášková and Krošlákova (2019) analyzed the challenges and strategies family firms take to establish themselves in international markets, which is becoming increasingly important in a globalized economy.

The articles reviewed also featured research on the use of artificial intelligence in the management of family businesses, as detailed by Wang and Li (2023). These authors emphasized that the use of modern technologies, such as AI, is key to increasing operational efficiency and improving decision-making processes in companies.

Also noteworthy are publications that have studied the various stages of development of family businesses, from their inception, through growth phases, to possible stages of crisis or stagnation. Shi, Yiping and He (2014) and Cucculelli and Peruzzi (2020) highlighted the dynamics of the development of these companies, analyzing the various paths taken by family businesses depending on internal and external conditions.

Scientometric analysis conducted by the authors using Scopus data showed that three particularly

relevant articles published after the analysis dealt with key topics related to the operation of family businesses, such as succession, leadership and management strategies, and the development of family businesses in times of pandemic crisis. Each of these publications makes a significant contribution to the literature on family businesses, revealing different aspects of their functioning under changing economic conditions.

The first article discussed, by Mikoláš and Matejun (2023), focuses on the succession process in family businesses. The authors analyze the challenges associated with the transfer of power and ownership in family businesses, as well as the implications for the long-term sustainability of these companies. The article details the various strategies used by family firms in the succession process, noting how crucial it is to properly educate and prepare the company's future leaders. Research also highlights the importance of cultural and interpersonal conditions that affect the effectiveness of the succession process.

The second article, by Apaydin, Sanda, Hoogendoorn and Eshak (2023), addresses leadership and management strategies in family businesses. The authors focus on the specific challenges faced by leaders in family businesses and the ways in which management strategies can be adapted to the unique characteristics of these businesses. The article pays particular attention to the role of the leader as the person responsible for organizational cohesion and long-term planning, while emphasizing that leadership in family businesses often requires a more flexible and empathetic approach.

The third article, by Siuta-Tokarska, Juchniewicz, Kowalik, Thier, and Gross-Golacka (2023), deals with the impact of the COVID-19 pandemic on the development of family businesses. The authors discuss how the pandemic crisis affected the functioning of family businesses and how these companies adapted their strategies in the face of global restrictions and economic challenges. The article details adaptation mechanisms, such as increased use of digital technologies, changes in team management, and the introduction of innovative solutions that helped family businesses survive in difficult economic conditions. The paper makes an important contribution to the literature that examines the impact of global crises on the performance of family businesses, particularly in terms of their resilience and adaptability.

Despite a significant increase in research interest in family businesses and issues related to the Fourth Industrial Revolution, including the competencies of Engineer 4.0, there is a noticeable research gap in

connecting these two areas. Analyzing the literature, it can be concluded that while the authors of numerous publications focus on specific aspects related to the management of family businesses and their transformation in the era of Industry 4.0, they do not attempt a deeper integration of these topics. An example is research on succession challenges in family businesses (Mikolaš & Matejun, 2023) and leadership and management strategy (Apaydin, Sand, Hoogendoorn & Eshak, 2023), which focuses mainly on management aspects, ignoring threads related to the technological requirements of Industry 4.0.

Similarly, analyses on the functioning of family businesses in the context of the COVID-19 pandemic (Siuta-Tokarska et al., 2023) focus on adaptive survival and growth strategies, but ignore issues related to the need for specific technological competencies of key employees, such as Engineers 4.0. Although competencies related to digitization and automation are crucial in the current economic context, their direct connection to the management of family businesses is not considered.

The lack of integration of these two key topics in the literature suggests the need for further research. In particular, an interesting research direction would be to analyze how family firms, which are characterized by specific management and cultural structures, adapt to the requirements of Industry 4.0 and to what extent they develop the engineering competencies necessary to function in this new technological era. This gap is particularly noticeable in the context of the role of Engineer 4.0, whose technical competence could be a key element in the success of family firms in a dynamically changing economic environment.

The research gap in Industry 4.0 competencies was also noted by Saniuk, Caganova and Saniuk (2021), who pointed to a disproportionately large number of studies on the changing demand for competencies in the areas of economics and management, compared to a much smaller number of studies focusing on the technical skills required for Industry 4.0. The changing economic and technological reality requires not only a redefinition of managerial skills but also of engineering skills, which are crucial in the modern industrial environment. For this reason, it is recommended to develop a universal and detailed model of competencies 4.0, which could help bridge the gap between different scientific disciplines and the practical areas of implementation of these competencies. This solution was proposed by Poszytek et al. (2023).

A competency model for 4.0 could provide concrete guidance for the education and training

system, which would better prepare future professionals and current employees for the challenges posed by Industry 4.0. An integrated competency model would include both technical and soft skills necessary for modern digitized companies. The results of such research could help shape curricula that meet the needs of the real market and the changing demands of technology. Research by Dumitrescu, Lima, Chattinnawat and Savu (2019) also highlights the importance of creating educational programs that will support the development of professionals ready to meet the challenges of Industry 4.0.

Research Methodology

The study verified the existence of significant relationships between the general characteristics of companies, such as the size of the company's employment, the scope of operations and the age of the company, and the perception of the usefulness of the specific competencies of Engineer 4.0 and Manager 4.0 by employees working in Polish family businesses. The aim of the study was to understand how these key characteristics of companies affect the assessment of the use of various competencies that are crucial in an Industry 4.0 environment.

Based on this analysis, the following hypotheses were formulated to verify the relationship between the variables:

H1: Employment size vs. strategic management evaluation. It is hypothesized that the size of employment affects employees' evaluation of the use of strategic management in Polish family businesses. Larger companies may value strategic planning more due to greater organizational complexity.

H2: Staff size vs. evaluation of the use of interdisciplinary knowledge. The hypothesis suggests that larger companies value interdisciplinary knowledge more because they require collaboration among different departments and specialists.

H3: Staff size vs. team building skills. It is assumed that larger companies will place more importance on team building skills, which may be necessary in more complex organizational structures.

H4: Scope of operations vs. evaluation of engineering knowledge utilization. The hypothesis suggests that companies with a broad scope of operations, especially in the technology sectors, value engineering competencies more among their employees.

H5: Business scope vs. working in interdisciplinary teams. Companies operating in

multiple fields are assumed to require their employees to work more often in interdisciplinary teams, which translates into a higher demand for such competencies.

H6: Business scope vs. management of a culturally diverse team. The hypothesis is that companies operating in international markets and culturally diverse environments value the ability to manage multicultural teams.

H7: Company age vs. valuation of engineering knowledge. It is assumed that younger companies, which are more flexible and dynamic, may value engineering knowledge more, which is essential in the modern technological environment.

H8: Company age and knowledge of artificial intelligence (AI). The hypothesis suggests that younger companies are more likely to implement new technologies such as artificial intelligence, which may influence a greater receptivity to such knowledge among employees.

H9: Company age versus openness to change. It is hypothesized that engineers employed by younger companies may be more open to change, which may be related to the greater dynamism and flexibility of these companies in adapting new solutions.

The survey was conducted using a pre-prepared survey questionnaire. The research population was defined as employees and owners of Polish family businesses that use elements of Industry 4.0 in their operation. The sampling process was conducted objectively and purposefully, according to established criteria. Individuals who met the following conditions were eligible for the survey.

- They were employees or owners of a Polish family business.
- They had at least a basic understanding of Industry 4.0.

The prepared questionnaire (39 questions, of which 30 were competency-related and 9 were metric-related) was designed to obtain information from respondents on their perception and use of Industry 4.0 elements in the company's daily operations. The survey procedure was carefully planned to ensure the objectivity and reliability of the results.

The size of the research population was determined on the basis of available data on the size of companies in Poland, provided by the Central Statistical Office (CSO), as well as on the share of family businesses in the total number of companies in Poland, as studied by Więcek-Janka and Lewandowska (2017). The sampling process for the study should be classified as mixed, purposive-typical, with the appropriate fractional proportions at 80%, which allowed to accurately reflect the specifics of the studied enterprises.

A confidence level of 95% was assumed for the survey and the maximum statistical error was assumed to be 5%. Based on these assumptions, the minimum required sample size was calculated, which was set at 176 units. In the process of the survey, responses were obtained from 178 family firms carrying out manufacturing (production) processes, which not only exceeded the minimum number of units, but also allowed for a more thorough analysis of the data. The empirical material thus collected met the criteria for being subjected to statistical analysis, while also ensuring that the results were representative in terms of general conclusions about family firms in Poland.

The raw data processing process, leading to information ready for analysis, has been divided in detail into two key phases: preparatory and computational. These phases are shown in Figure 1 to illustrate the logic and sequence of the data transformation activities.

During the preparatory phase, the main focus was cleaning the data of inaccuracies, omissions, or outliers. Data standardization was also done at this stage, ensuring consistency in the format and coverage of individual variables. The coding of qualitative variables was also key here, as well as a preliminary analysis to identify potential problems of data completeness and quality.

The next step was the computational phase, which involved performing statistical and mathematical operations on the prepared data. At this stage, appropriate statistical measures were applied, enabling comparative and correlational analysis to be carried out, according to the research assumptions made. The purpose of this stage was not only to calculate basic descriptive statistics but also to identify significant correlations between variables that would allow conclusions to be drawn about the problem under study.

Figure 4 presents the entire process graphically, illustrating the transition from raw data to final analysis results, indicating the key operations carried out in each phase. This complex approach has allowed for consistent and reliable results, which form the basis for further analysis and interpretation of the data.

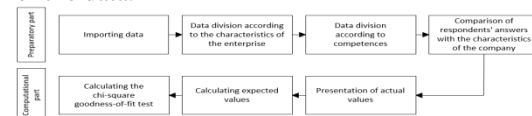


Fig. 4: Summary of the responses of the respondents with the scope of the company's operations for engineering knowledge competencies.

The responses collected from 178 respondents were imported into a summary sheet in MS Excel, where they were sorted according to the characteristics of the companies that were obtained in the metrics section of the survey. In particular, the following variables were taken into account: the age of the company, the scope of operations, and the size of employment. This ordering allowed the data to be systematized and prepared for further analysis.

In the next step, corresponding tables were created for each of the competencies studied, such as Table 1, which juxtaposed respondents' answers on a six-point Likert scale with company characteristics. The Likert scale, used to assess competencies, made it possible to accurately estimate the level of employees' perceptions of the usefulness of specific competencies depending on the characteristics of the enterprise. Each table took into account the values corresponding to each rating, which allowed for subsequent statistical calculations.

The resulting data was then subjected to quantitative analysis by summing the values in both rows and columns. These totals provided general information on the distribution of competency assessments in different categories of companies, which enabled further statistical analyzes. The summed values were key to understanding what enterprise characteristics (e.g., employment size or company age) affect the suitability ratings of specific Engineer 4.0 and Manager 4.0 competencies.

Table 1: Summary of the answers of the respondents answers of the respondents with the scope of the company's operations for engineering knowledge competencies.

Scope of operations	Rating						Sum of columns
	1	2	3	4	5	6	
european	0	3	4	8	12	5	32
global	0	0	1	4	5	6	16
national	0	2	4	8	11	13	38
local	6	6	11	10	13	6	52
regional	0	2	11	9	8	10	40
Sum of rows	6	13	31	39	49	40	178

The next stage of working with the data resulted in the calculation of expected values for the engineering knowledge competency. These values were obtained by calculating the product of the sum of the rows and the sum of the columns for each response and then dividing this product by the total number of responses. This determined the theoretical number of responses that would be expected if there were no correlations between the variables, i.e. the characteristics of the companies and the competency assessment.

The final step in the data analysis was to conduct a chi-square consistency test. This test consisted of calculating the difference between the observed values (X) and the expected values (Y) for each response to competency in engineering knowledge. This difference was squared, and then the quotient of this difference and the expected value were summed. The result of the chi-square test allowed us to assess whether the differences between the observed and expected scores were significant enough to reject the null hypothesis of no relationship.

The chosen method of calculation was to determine the statistical consistency of the results obtained with the research assumptions. This analysis allows us to verify whether the characteristics of family businesses (such as employment size, scope of operations, and age of the company) affect the assessment of the usefulness of technical competencies, such as engineering knowledge, in the context of Industry 4.0.

Results

The statistical analyzes conducted, based on the results of the chi-square test, made it possible to verify the research hypotheses on the influence of various characteristics of Polish family businesses on the assessment of the usefulness of selected competencies of Engineer 4.0 and Manager 4.0. The study aimed to verify how factors such as the size of employment, the scope of activity, and the age of the company affect the perception of competencies in the context of Industry 4.0.

Of the nine hypotheses tested, four were confirmed, suggesting that, for these cases, there is a statistically significant relationship between business characteristics and the assessment of competence suitability. The results of the chi-square test indicate that the confirmed hypotheses are primarily related to the effect of the size of the job on the assessment of strategic management and team building skills, as well as the effect of the scope of the company on perceptions of working in interdisciplinary teams and leading multicultural teams.

The remaining five hypotheses were not confirmed, suggesting that there was no statistically significant relationship between the variables studied in these cases. This may mean that other factors, not directly related to company characteristics, may have a greater impact on the evaluation of these competencies.

Table 2 presents a detailed summary of the results of the chi-square test for all hypotheses tested, which allows a more detailed analysis of the

results. This table includes both the values of the chi-square statistics and the significance levels, which made it possible to assess the consistency of the results with the research assumptions.

Table 2: Summary of the results of the chi-square test for individual hypotheses

Hypothesis	Chi-squared	Severity Level	Critical value	Conclusion
H1	34.548	0.05	31.410	Confirmed
H2	14.546	0.05	31.410	Rejected
H3	25.359	0.05	31.410	Rejected
H4	33.150	0.05	31.410	Confirmed
H5	37.236	0.05	31.410	Confirmed
H6	28.574	0.05	31.410	Rejected
H7	40.551	0.05	37.653	Confirmed
H8	37.524	0.05	37.653	Rejected
H9	20.568	0.05	37.653	Rejected

The results of the study provide interesting conclusions on the impact of selected characteristics of Polish family businesses on the evaluation of key aspects of management and skills related to Industry 4.0. The analysis of the results allowed for a better understanding of how the characteristics of enterprises, such as the size of employment, the scope of activity, and the age of the company, affect the perception and use of modern competencies in both technical and managerial areas.

Confirmation of Hypothesis H1 underscores the important role of employment size in shaping employees' views on strategic management. The results indicate that in larger companies, employees attach more importance to strategic actions taken by management. This may be due to more complex organizational structures and a broader scale of operations that require strategic planning to ensure efficiency and alignment with company goals.

In contrast, the rejection of hypothesis H2 suggests that the size of the workforce does not significantly affect the evaluation of certain aspects of management, such as the use of interdisciplinary knowledge. This may indicate that factors such as organizational culture, leadership style, or industry specifics may play a greater role in perceptions of this aspect of management than the sheer number of employees.

Similarly, rejection of hypothesis H3 indicates that the number of employees does not have a significant impact on team-building skills. This suggests that the ability to successfully build teams may depend more on individual characteristics of managers, such as interpersonal skills and group dynamics, than on the size of the company as a whole.

The importance of a company's scope of operations was confirmed for hypotheses H4 and H5, highlighting its impact on the evaluation of engineering knowledge and working in interdisciplinary teams. Companies with a wide scope of operations may require more advanced

technical knowledge and cooperation between different specialists, which translates into higher employee ratings of these competencies. A broad scope of operations may be associated with more complex technologies and processes that require an interdisciplinary approach and in-depth engineering knowledge.

The rejection of hypothesis H6 suggests that the scope of business does not affect all aspects of competency assessment, including the ability to manage a culturally diverse team. This may indicate that not all companies, even those with a broad scope of operations, engage in international collaboration or do not require advanced skills to manage multicultural teams.

The age of an enterprise, as shown by the confirmation of hypothesis H7, has a significant impact on the evaluation of engineering knowledge. Older companies, due to their greater experience and established position in the market, may have deeper technical knowledge and developed technological processes, which translates into a higher evaluation of this knowledge by employees.

However, rejection of Hypotheses H8 and H9 indicates that a company's age does not significantly affect its assessment of artificial intelligence (AI) knowledge or openness to change. This suggests that a company's ability to adapt to new technologies such as AI and its readiness for change depend more on the company's current strategy and innovation culture than on its length of operation in the market. Older companies may find it more difficult to adapt to new technologies, but it is not age, but organizational flexibility and openness to innovation that play a key role in this process.

Although not all research hypotheses were confirmed, the results of the study provide important information on the relationship between the characteristics of Polish family businesses and the assessment of the importance of the selected competencies of Engineer 4.0 and Manager 4.0. The chi-square test, the results of which are presented in Table 3, showed the existence of a relationship between selected business characteristics and specific competencies. These results provide a clearer understanding of how the size, scope of operations, and age of the company affect the perception of key competencies in the context of Industry 4.0.

An interesting result was the relationship between the age of the company and the evaluation of basic mechanical engineering knowledge. These results suggest that older companies that have been in business for a longer period of time may value traditional engineering competencies, such as mechanical knowledge, more due to their well-

established technical practices and long-term experience in technical operations.

The scope of a company's operations, on the other hand, proved to be an important factor in assessing knowledge of artificial intelligence (AI). Companies operating in a wider scope, especially those operating in international markets, may be more interested in modern technologies such as AI, as a result of the need to adapt to new technologies in different sectors. Furthermore, the scope of operations also influenced the assessment of project management, which may suggest that a greater number of diverse projects requires advanced management skills in companies with broader operations.

Additionally, the size of the workforce affected the assessment of competencies related to cross-cultural knowledge and time management. Companies with more employees may encounter greater cultural diversity in their teams, increasing the need for competencies to effectively manage culturally diverse teams. Time management, on the other hand, may be more relevant in larger companies, where the scale of operations and complexity of processes require effective work organization and scheduling.

Table 3. Summary of significant chi-square results

feature	competence							
	basic knowledge of mechanical engineering	engineering knowledge	knowledge about AI (artificial intelligence)	work in interdisciplinary teams	project management	knowledge of different cultures	time management	strategic management
company age	39 236	40 551						
scope of activity		31 150	39 889	37 236	36 809	37 882		
employment size						32 101	35 330	34 548

In addition, in order to better understand the results, illustrative summaries of the percentage of respondents' answers were made. It is worth mentioning that the number of companies in each category was not equal, so to obtain meaningful data, the number of individual evaluations was compared to the total number of responses in each category.

Economic development and increasing globalization make cross-cultural competence an increasingly important element of management in companies, especially those operating in foreign markets. The results of percentage surveys, which juxtapose the size of the workforce with the level of knowledge about different cultures, show interesting variations in the assessment of this competency depending on the size of the company.

In companies with 50 to 249 employees, the most frequently selected rating was 5, indicating a high rating for knowledge and understanding of cross-cultural aspects. This may indicate that medium-sized companies, which often already deal with foreign contractors, are beginning to recognize the

need to develop cultural diversity competencies, although they are not yet as large-scale as the largest corporations.

In companies with 250 to 499 employees, 60% of the respondents indicated a rating of 3, suggesting a moderate understanding and implementation of cross-cultural competencies. These companies may operate at the intersection of international markets, but do not necessarily pay much attention to these skills at the operational level. Surprisingly, there was a discrepancy in the ratings in the largest organizations (more than 500 employees), where 25% of the respondents rated these competencies at 2, and another 25% rated them at 5. This discrepancy may be indicative of differing attitudes within these companies; some departments or teams may make intensive use of intercultural skills, while others may not place as much importance on them.

For small companies with fewer than 50 employees, most of the respondents indicated a rating of 4, indicating a relatively high assessment of these competencies. It seems that these smaller companies are beginning to understand the value of cross-cultural competency, especially if they operate in markets with high cultural diversity. In microenterprises (with fewer than 10 employees), the highest number of responses also fell on a rating of 4, but the second most frequently selected score was 1, which may suggest that there is a fair amount of variance in such companies' assessment of the importance of these competencies. This is likely due to limited exposure to foreign markets and international cooperation among the smallest entities.

The trend indicating that larger companies are more likely to recognize the need to develop cross-cultural competence is understandable. Operating in an international environment, they need to communicate effectively with partners from different cultures, which allows them to build their competitive advantage. Understanding cultural differences affects the effectiveness of negotiations, the management of teams, and the building of long-term business relationships. Smaller companies that do not have such extensive international operations may not see the need at this time. However, this may limit their ability to grow and expand into new markets, which is crucial in the context of continued globalization and competitiveness.

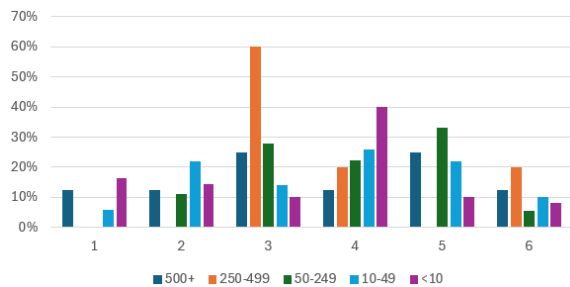


Fig. 5. Percentage comparisons of responses on "employment size and knowledge of different cultures"

Strategic management is another key competency in Industry 4.0 that allows effective adaptation to a rapidly changing market environment. The results of the survey indicate that most of the respondents' ratings for this skill are between 4 and 6 on a six-point scale. This suggests a high awareness of the importance of strategic management in Polish family businesses.

Analysis of the results shows that 44% of medium-sized companies (with 50 to 249 employees) rated this competency at 6, suggesting that these companies are fully aware of the need for strategic management as a key tool that enables them not only to grow stably, but also to adapt flexibly to market and technological changes. For medium-sized companies, strategy is an essential element that allows them to effectively manage resources and plan future activities in a way that is safe and consistent with the company's long-term goals.

Large companies, with 250 to 499 employees, most often chose ratings of 5 and 6, which also indicates their high awareness of strategic management. These companies, operating on a larger scale and in more competitive markets, must implement strategies that allow them to remain competitive and respond quickly to changing market conditions. Strategic management is therefore a key tool that enables these organizations to plan effectively and achieve their long-term goals.

However, 63% of the largest companies (with more than 500 employees) rated strategic management a 4, which may suggest some challenges these organizations face. In large companies, which often have a stable market position, a sense of security can reduce the perceived need for continuous improvement of the strategy, which could result in a lower rating. Alternatively, a lower rating can indicate challenges associated with managing very large organizational structures, where implementing a coherent and effective strategy can be more complicated and time consuming.

For small companies (with 10 to 49 employees), responses oscillated between ratings of 4 and 6, suggesting that these companies understand the importance of strategic management for their development, even if the scale of their operations is smaller. For small companies, strategy can be a key factor to enabling them to continue to grow and remain competitive in the market.

Microenterprises (with fewer than 10 employees) most often rated this competency at 5, also indicating an understanding of the importance of strategic management. Although their resources and scale of operations are limited, microenterprises also recognize the need to have a clear strategy to thrive in a competitive environment.

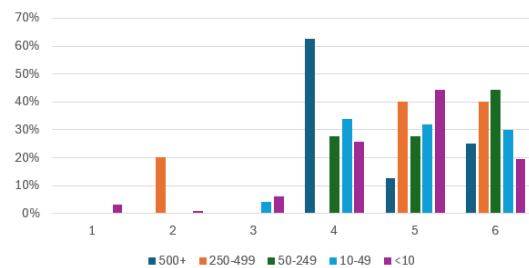


Fig. 6. Percentage comparisons of responses on "employment size and strategic management"

Time management is one of the most important individual skills for engineers and managers alike, especially in the rapidly changing work environment offered by Industry 4.0. The ability to manage time effectively becomes crucial when organizations must operate at the rapid pace of technological change and increasing market demands.

Based on the data presented in Figure 6, there is a clear upward trend in the assessment of the importance of time management in companies of different sizes. The results show variation in the perception of this competence, which may depend on the availability of resources and the operational specifics of the companies.

Microenterprises (with less than 10 employees) rated time management at 70% with a score of 6, suggesting that in small businesses, where human resources are limited, the ability to manage time effectively becomes indispensable. For microenterprises, time is one of the most important resources that must be properly utilized to meet business goals and remain competitive in the market.

Small businesses (with 10 to 49 employees) also indicated a high rating for time management, with 62% of respondents rating this competency at 6. This result is similar to that of micro-enterprises, suggesting that small businesses, like micro-

enterprises, need to use available time resources effectively to meet their goals, especially when operating on a limited budget and with a smaller team.

For large corporations (with more than 500 employees), respondents' answers were more varied. 38% of the respondents rated time management a 6, suggesting that in large organizations, effective time management is considered important, especially at the operational level. However, larger companies, due to their organizational structure, may have different approaches to time management, which influences the variation in results.

In medium-sized companies (with 50 to 249 employees), as much as 50% of respondents indicated a rating of 5, suggesting that these companies place a high value on time management, but may not rate this skill as absolutely crucial. Similarly, in companies with 250 to 499 employees, 80% of the respondents rated time management at 5 and 6, indicating that these companies also recognize the need for effective time management, but approaches may vary depending on the size of their teams and the specifics of their business.

Variation in assessments in larger companies can indicate different approaches to time management depending on the specifics of the company and its internal management structures. In large corporations, time may be managed more at the managerial level, while in smaller companies, the need to manage time affects every employee, making this competency more relevant at all levels of the organization.

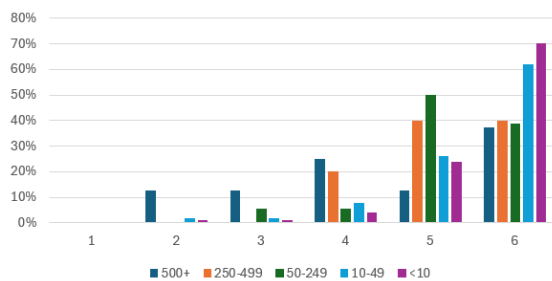


Fig. 7. Percentage comparisons of responses to "employment size and time management."

The most significant correlations between the competencies studied and the characteristics of the companies occurred with respect to the scope of the company's operations, as shown in Table 5. In the context of Industry 4.0, engineering expertise is a key determinant of companies' ability to innovate and adapt to new technologies. The analysis of the results indicates that the evaluations of employees of

family businesses vary depending on the scale of the company's operations, which may have an impact on the perception of the importance of having technical expertise.

Local family businesses showed the greatest variation in their assessment of the usefulness of engineering knowledge. In this category, the employee evaluations were broadly divided, from 1 to 6. The most frequently selected rating was 5, indicated by 25% of the respondents, which may suggest that some local companies see value in this competency, but do not necessarily view it as absolutely crucial. Interestingly, local companies were the only ones to indicate a rating of 1 in 12% of cases, which may mean that some of these companies do not see engineering expertise as an important factor for their operations, perhaps due to the lack of direct technological competition in the local market.

Similar variation in ratings occurred in companies with a regional footprint, where employees chose ratings of 3 to 6 with a frequency of 20% to 28%. In this case, the lack of a clear position may be due to the fact that these companies operate in a more limited regional context, where competition may be less intense than in national or global markets. As a result, the need to innovate may be perceived as less urgent, which affects the evaluations of the usefulness of engineering knowledge.

Domestic and global companies showed significantly higher scores, indicating greater awareness of the need for advanced technical knowledge. In domestic companies, up to 34% of the respondents rated the usefulness of engineering knowledge at 6, while in global companies this answer was selected by 38% of the respondents. The second most frequently selected rating was 5, suggesting that in large-scale companies, engineering knowledge is seen as a critical component of a company's ability to grow and compete in international markets. The awareness of the need for continuous development and specialization in the technology area is more pronounced in those companies where innovation is the key to maintaining competitiveness.

European companies, on the other hand, showed a rating of 5 in 38% of the cases, which also indicates a strong need for engineering expertise, although this may reflect a more balanced approach to technology, where the rating does not yet reach the highest level. This may be due to the characteristics of European markets, where technology competition is intense, but the need for innovation varies by sector.

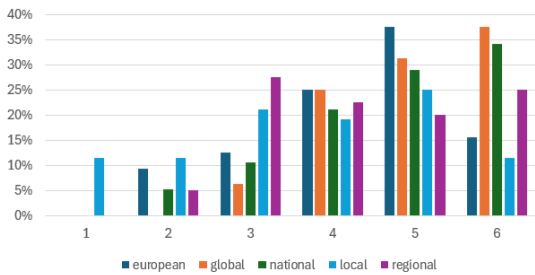


Fig. 8. Percentage comparisons of responses on "scope of activity and engineering knowledge"

Artificial intelligence (AI) is increasingly influencing various aspects of business, from process automation to data analysis and decision-making. The results of surveys that evaluated the knowledge of AI among employees of companies of different sizes and scope of business show a clear variation in the perception of the usefulness of this competence.

In regional companies, up to 35% of the respondents considered AI knowledge to be of low importance, reflecting a certain reserve toward new technologies in smaller organizations that are not directly exposed to international competition. Similar trends can be observed in local companies, where 42% of the responses indicated a low relevance of this competency, with the highest number of ratings falling in the range of 1-2. This may be due to a lower need for process automation and limited access to advanced technologies in these companies, which often operate in traditional industries where AI is not yet a key tool.

On the other hand, in global and European companies, the scores are much higher. 44% of global companies' respondents rated the usefulness of AI knowledge at 4, and 31% of European companies indicated a rating of 5. The high ratings in these groups of companies may be due to the need to adapt to global competition, which requires optimizing business processes and implementing technological innovations to remain competitive. These companies see the value of AI in increasing operational efficiency, automating tasks, and creating new products and services based on advanced data analysis.

Domestic companies are also seeing high ratings for AI knowledge, with more than 60% of respondents giving this competency a rating of 4 or higher. These results indicate that companies operating in the broad domestic market recognize the potential of artificial intelligence as a tool to support innovation, enable better resource management, and increase operational efficiency.

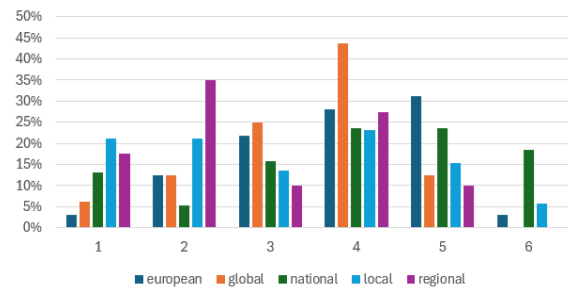


Fig. 9. Percentage comparisons of responses on "scope of activity and knowledge of AI"

The fourth industrial revolution is characterized by the integration of different fields of knowledge and increasingly strong global collaboration. As a result, working in interdisciplinary and multicultural teams is becoming one of the key competencies in Industry 4.0. Studies have shown that assessments of this competency vary significantly across the range of companies, highlighting the varying approaches to this skill depending on the scale of operations.

Among local companies, the majority of responses ranged from 1 to 5, and these ratings were evenly distributed, with frequencies ranging from 15% to 21%. This spread of ratings may indicate that locally operating companies are less likely to feel an immediate need to work in diverse interdisciplinary teams, as their operations are mainly focused on domestic markets, where cultural diversity and interdisciplinarity may not be key challenges.

Regional companies, on the other hand, focused mainly on ratings of 3 and 4, which accounted for 33% and 30% of all responses, respectively. These results suggest that regional companies are beginning to recognize the benefits of working in interdisciplinary teams, especially as they expand into new markets within the region. However, interdisciplinarity and multiculturalism are not yet fully integrated into their work structures.

The highest ratings for this competency were received by European and domestic companies, where the majority of respondents rated working with interdisciplinary teams at 5. This indicates a greater awareness and demand for these skills, as a result of large-scale operations, both within the domestic market and internationally within Europe. For these companies, working with multicultural and interdisciplinary teams is an essential part of their daily operations, allowing them to remain competitive and innovate effectively.

Global companies also placed a high value on this competency, with ratings oscillating between 4 and 5, which accounted for almost 70% of all

responses. For global organizations that work with partners from all over the world, the ability to work effectively in diverse teams is crucial. Interdisciplinarity allows for faster problem solving and cultural diversity increases creativity and innovation, which has a direct bearing on success in the international market.

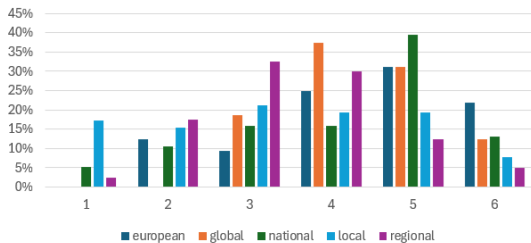


Fig. 10. Percentage comparisons of responses on "scope of activity and work in interdisciplinary and multicultural teams."

Nowadays, most of the activities undertaken by organizations are based on projects that achieve strategic goals and innovate. Effective project management allows for better planning, control, and execution of tasks, which, in turn, minimizes the risk of failure and increases the efficiency of operations. Assessments of this competence vary depending on the scale of companies' operations, suggesting a differentiated approach to project management depending on the specifics of companies' activities.

In local companies, the dominant rating for this competency was 6, chosen by 19% of respondents, indicating a group of companies that see project management as crucial to their development. At the same time, there is a noticeable high number of ratings of 1 and 2, which amounted to 15% and 12%, respectively, which may suggest that some local companies do not place enough importance on this skill, perhaps due to the smaller scale of operations and limited resources.

Regional companies showed greater variation in ratings, with up to 33% of respondents rating project management with 6, indicating a growing awareness of the importance of this competency in more established structures. In addition, ratings of 3 and 4 were chosen with a frequency of 21%, indicating that not all regional companies have yet reached an advanced level in project management, but realize their importance.

In domestic companies, nearly 60% of the respondents rated project management at 5 or 6, indicating a clear understanding of the importance of this competency in the context of implementing large national projects. These companies have to coordinate numerous projects on a larger scale,

which requires advanced management and effective organization.

The most common ratings in European organizations were 5 (in 38% of cases) and 6 (in 28% of cases), suggesting that these companies appreciate the importance of project management in the context of operating in international markets. These companies have to deal with a wide range of complex projects, which often require coordinating activities between different teams and taking into account the varying legal and cultural regulations in different European countries.

Global companies also place a high value on project management, as evidenced by ratings of 5 and 6, with frequencies of 32% and 28%, respectively. These results show that large-scale organizations need advanced project management to effectively execute complex multiphase projects that often require coordination among multiple teams in different geographic locations. In these companies, project management is becoming a critical enabler for timely and effective execution of strategic initiatives, ultimately helping to remain competitive in global markets.

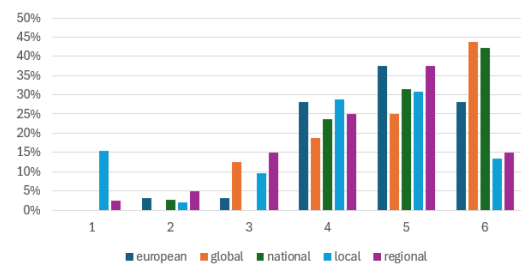


Fig. 11. Percentage comparisons of responses on "scope of activity and project management."

Knowledge of different cultures plays a key role in effective communication and building business relationships in an international environment. It helps avoid misunderstandings due to cultural differences and better understand the needs and expectations of stakeholders from different parts of the world. An analysis of the assessments of this competency among employees of companies with different scopes of operations reveals differing attitudes toward its value.

In global companies, up to 50% of respondents gave knowledge of different cultures a rating of 3, suggesting that despite the international scale of the organization, half of the employees do not consider this competency essential. It is also surprising that none of the respondents in this category rated this competency a 6, which could mean that global companies do not always fully appreciate the

importance of cross-cultural knowledge in their day-to-day operations, even though their scale of operations often requires working with diverse partners from different parts of the world.

For local and regional companies, 40% of employees in both categories rated knowledge of different cultures at 4, which may suggest a moderate perception of this skill. At the same time, combined responses in the range of ratings 1-3 in both groups are also around 40%, showing that for many employees of local and regional companies, knowledge of different cultures is not considered crucial. This may be due to a lesser exposure to international markets, where this skill is most useful.

The highest ratings for this competency come from employees of European companies, with about 70% of responses ranging from 4 to 6, indicating a clear recognition of the value of cultural knowledge in international operations. European companies, due to their operations in diverse markets within Europe, where international cooperation and cultural diversity are indispensable, clearly recognize the need for these skills.

Similar trends can be seen in domestic companies, where a high rating for cross-cultural knowledge is also noticeable, with most responses concentrated in the range of 4-6. These companies operate in a broad domestic market, which can require collaboration with a variety of partners, both inside and outside of the country, underscoring the importance of this competency.

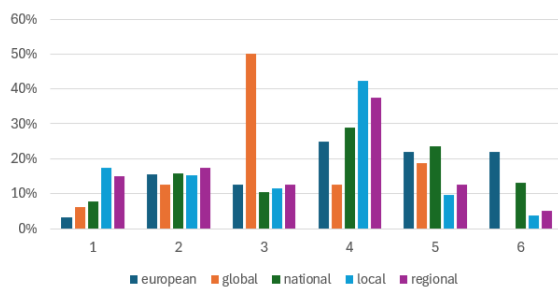


Fig. 12. Percentage comparisons of responses on "scope of activity and knowledge of different cultures"

Competencies whose ratings depended on the age of the company were basic mechanical engineering knowledge and general engineering knowledge. Percentage results for respondents' evaluations of both of these skills show similar trends, suggesting that older companies have a more established approach to technical competencies, including mechanical engineering.

The largest number of responses indicating a rating of 6 came from companies operating between

31 and 40 years. These companies rated the importance of engineering knowledge highest, which may be a result of their long-term experience and the need to maintain a competitive advantage by investing in advanced technical competence. These companies, based on their experience, may be more oriented toward using technical knowledge to innovate and maintain high-quality production or services.

The oldest companies, operating between 41 and 50 years and more than 50 years, gave this competency mainly 5 and 6, indicating their strong understanding of the value of engineering knowledge. In these companies, engineering knowledge is likely to be well established as a key resource to maintain a high level of technology and innovation.

In contrast, younger companies, in the age range of 11 to 20 years and less than 10 years, assigned scores of 3-5 to this competency. This may mean that these companies are just developing their technical resources and do not yet have such a strong engineering background. These companies may be more focused on organizational and business development, with less emphasis on technical expertise, which may be due to their shorter tenure in the market and less experience in the technology industry.

In summary, older companies show greater appreciation for engineering expertise, which may be related to their long-term development and greater experience in using advanced technologies. Younger companies, while acknowledging the importance of this competence, show less sophistication in its practical use.

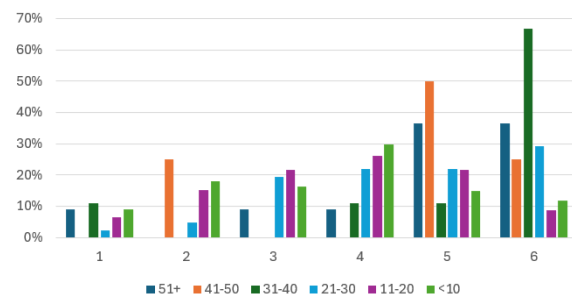


Fig. 13. Percentage comparisons of responses on "company age and basic knowledge of mechanical engineering"

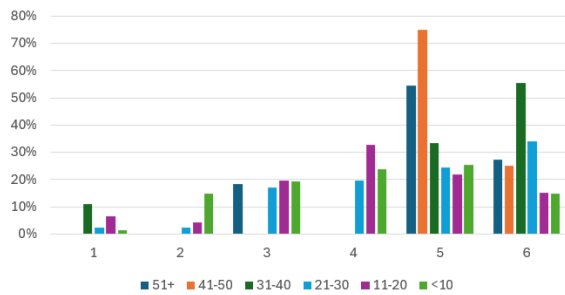


Fig. 14. Percentage comparisons of responses on "company age and engineering knowledge"

Summarizing the percentages analyzed, it can be seen that larger family businesses, with a broader scope of operations and longer tenure, value advanced competencies such as strategic management, engineering expertise and working in interdisciplinary teams more highly than micro and small businesses. This may be due to the more complex organizational structures in larger companies that require the specialized knowledge and skills necessary to manage effectively in changing market conditions. In these companies, these competencies play a key role in ensuring stability, growth, and innovation.

On the other hand, smaller companies, especially microenterprises, place the greatest importance on time management, a key competency in small teamwork, where proper task scheduling and efficient use of human resources can determine success. Smaller companies may also place less emphasis on advanced technical competencies as a result of the limited scale of operations and resources.

The results of the survey indicate that engineering competencies such as knowledge of artificial intelligence (AI), engineering knowledge, or basic mechanical engineering knowledge are particularly valued by older companies operating on a national, European, and regional scale. These companies, due to their experience and scale of operations, have a greater need for high-tech resources that enable them to grow and compete in more demanding markets.

However, when summarizing the analysis of the results, the limitations of the study should be taken into account. It concerned only Polish family businesses, which limits the ability to generalize the conclusions to an international scale. However, the use of a quantitative research approach allowed an overall assessment and generalization of the conclusions, thanks to the statistical identification of the relationships between the characteristics studied. However, the complexity of each of the phenomena

analyzed suggests the need for separate and more detailed studies that will allow in-depth identification of specific factors affecting various competencies in family businesses.

Discussion

The results of the study confirmed that different characteristics of family businesses have a significant impact on the assessment of the usefulness of selected competencies related to Industry 4.0. These relationships were particularly evident for the size of the workforce, the scope of operations, and the age of the company. These results are in line with the literature, which emphasizes that organizational characteristics have a significant impact on how companies adapt to technological change and innovate (Kazancoglu et al., 2021).

Confirmation of Hypothesis H1 suggests that the size of an organization influences the assessment of competencies related to strategic management. As previous research indicates, larger companies are characterized by more complex organizational structures, which requires more sophisticated strategic management tools to effectively coordinate activities (Mikoláš & Matejun, 2023). In larger family businesses, strategic management plays a key role in long-term planning, which is essential to remain competitive in rapidly changing markets (Apaydin et al. 2023).

The relationship between the scope of operations and the assessment of competencies related to engineering knowledge (hypothesis H4) suggests that companies operating on a larger scale value technical expertise more highly. This is consistent with research that indicates that companies operating in larger markets are more likely to face stronger competition and need to introduce more advanced technologies to maintain their position (Cucculelli et al., 2022). These companies often need to invest in innovative technology solutions and work with interdisciplinary teams, which requires adequate engineering expertise (Wang & Li, 2023).

Confirmation of Hypothesis H5 indicates that companies with a broader scope of operations are more likely to engage in interdisciplinary teams. As demonstrated in the literature, these companies, especially those operating in international markets, need to integrate different areas of knowledge and skills in order to effectively implement complex projects (Siuta-Tokarska et al., 2023). This requires the ability of specialists from different fields to work together to effectively innovate and optimize production processes (Panda et al., 2020).

The confirmation of Hypothesis H7, which indicates a greater appreciation of engineering knowledge by older companies, can be explained by their long-term experience and stability. Older companies often have deep-rooted technological processes and value engineering knowledge as a key component of their operations (Cucculelli & Peruzzi, 2020). As research indicates, older companies tend to take a more conservative approach to innovation, which means that they invest in proven technologies that provide them with long-term stability (Shi et al., 2014).

The findings, in line with the literature, indicate that the size of the workforce, the scope of the business, and the age of the business are key to assessing competencies related to Industry 4.0. These relationships underscore how important it is to tailor knowledge and skill resources to the specific needs of family businesses, which is in line with previous research (Poszytek et al., 2023). Further research in this area should focus on a more detailed analysis of individual competencies to identify the specific needs of different groups of businesses.

Other results obtained during the study revealed significant relationships between employment size, company age, and scope of operations and the evaluation of other competencies related to Industry 4.0. These relationships indicate that the impact of various company characteristics on competency assessment may be more complex than initially thought. The complexity of these relationships confirms previous research that indicates that various characteristics of family businesses can influence decision making and adaptation processes in the context of new technologies (Siuta-Tokarska et al., 2023).

The link between the age of the company and the assessment of basic mechanical engineering knowledge can be explained similarly to the assessment of engineering knowledge competencies. Older companies, with a longer tenure in the market, have more experience, which translates into a higher rating of the importance of these competencies. This is due to the fact that older family businesses, due to their long-term operation, have had to adapt to technological changes at some point, forcing them to expand and deepen their technical knowledge (Cucculelli & Peruzzi, 2020). This approach to technical knowledge, especially in the areas of mechanical engineering, allows companies to make better use of the available technological resources, which increases their competitiveness in the market (Shi et al., 2014).

On the other hand, the characteristic of companies related to the scope of operations

influenced the rating of competencies such as knowledge of artificial intelligence (AI) and project management. Companies operating on a national, global and European scale rated these competencies significantly higher than local or regional companies. This correlation may be due to the complexity of projects and greater competition in broad markets. Companies operating in international markets must not only introduce the latest technologies, but also skillfully manage complex projects that often require interdisciplinary collaboration and the use of modern technological tools (Wang & Li, 2023). Project management and the implementation of AI is becoming an indispensable part of the operation of large companies that want to maintain their position in intense global competition (Pini, 2019).

The size of the workforce also mattered in assessing competencies such as cross-cultural knowledge and time management. Smaller companies, particularly micro- and small companies, were less agreeing on the importance of cross-cultural knowledge. Teams in such companies tend to have less culturally diverse employees, which influences a less need to develop cross-cultural competencies (Apaydin et al., 2023). On the contrary, larger companies that operate in more globalized sectors must place greater importance on managing cultural diversity, which is a key factor for them to succeed in an international environment (Kazancoglu et al., 2021).

Similar differences can be observed in the case of time management, where micro and small companies rated this competency higher than larger companies. In small companies, due to less complex organizational structures and smaller project teams, proper time management plays a key role in work efficiency. Employees of smaller companies often need to better organize their time to efficiently complete tasks with limited resources, making time management one of the most important competencies in such companies (Cucculelli et al., 2022).

In conclusion, the study confirmed that the various characteristics of family businesses, such as the size of the workforce, the age of the company and the scope of operations, have a significant impact on the assessment of individual competencies related to Industry 4.0. The complexity of these relationships underscores how diverse the needs of companies are depending on their size, experience, and scale of operations. These findings are consistent with previous research indicating the importance of matching knowledge and skill resources with the specific requirements of companies (Poszytek et al., 2023).

However, the study has some limitations that must be taken into account when interpreting the results. First, the analysis focused only on Polish family businesses, which limits the generalizability of the conclusions to other markets and cultures. Although Poland has an extensive family business sector, the results may not fully reflect the reality of family businesses in other countries with different economic structures and market conditions. In addition, the use of a quantitative approach only allows for statistical analysis of relationships without providing full information on the reasons or mechanisms behind the observed relationships. Finally, the survey sample was limited to 178 respondents, which may affect the statistical power of the analysis and the generality of the conclusions.

Conclusions

The study confirmed significant relationships between the characteristics of Polish family businesses and the assessment of key competencies related to Industry 4.0. The results clearly indicate that the size of the company, its age, and the scope of its operations have a significant impact on the perception of the value of such skills as strategic management, engineering knowledge, artificial intelligence (AI) knowledge, and working in interdisciplinary teams. Older firms and those operating on a larger scale have been shown to value advanced technical competencies and project management more, which is consistent with the results of previous research on family businesses (Cucculelli & Peruzzi, 2020; Wang & Li, 2023). Smaller and younger companies, on the other hand, focus more on effective time management, reflecting their need for flexibility and operational efficiency with limited resources.

The survey results also indicate that companies operating on a national, European, and global scale have significantly higher scores on competencies such as project management and AI knowledge compared to local and regional companies. This correlation may be due to more complex projects and tougher competition in international markets, where modern technology and advanced management are becoming key to maintaining competitiveness.

The identified limitations point to the need for continued research on the relationship between business characteristics and competence assessment. In the future, it would be worthwhile to conduct qualitative research that would allow an in-depth analysis of the mechanisms that influence the assessment of competence. Interviews with owners and employees of family businesses could provide

valuable information on how different characteristics of companies affect the management of technical and organizational competencies.

Further research could also include cross-cultural comparisons, analyzing how family businesses in different countries assess competencies related to Industry 4.0. Such research would allow an assessment of to what extent the results obtained in Poland are characteristic of other countries and to what extent they are specific to local economic conditions. It would also be worth considering conducting research based on a larger sample of respondents to increase the representativeness of the results and their statistical significance.

In conclusion, future research should focus on a more complex and interdisciplinary approach to analyzing the competencies of family businesses, which will provide a deeper understanding of the role played by different characteristics of companies in shaping their growth strategies in the era of Industry 4.0.

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