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A framework for assessing digital maturity at higher education institutions

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Abstract
Digital technologies and the emergence of generalized artificial intelligence are paving the way for a profound transformation in education. Despite this transformation and increasing adoption of digital technologies in higher education institutions (HEI), a comprehensive model to assess digital maturity (DM) and identify areas for improvement remains a critical gap. This mixed-method study introduces a novel approach for assessing DM in HEI. The research used the Picture Fuzzy (PF) SWARA method to assess digital maturity levels and identify potential development areas. The model's merit is evaluated with a case study on a HEI in Eastern Europe where academics and administrative units are interviewed (n = 32) on the university's digitalization initiatives. Building upon interview outputs, a survey covering six main and 24 sub-dimensions is run to 212 participants. The results indicate that the DM level of the university is e-Confident with a score of 71.26, representing effective use of digital tools in the institution with some potential improvement areas. The most significant achievement is observed in academic research, followed by online education and training. However, digitalization in student admissions, online learning, graduation processes, documentation, and archiving need further enhancement. The findings offer valuable insights for HEI to pinpoint critical areas of improvement in their digitalization efforts.

Keywords Digital transformation, Fermatean fuzzy, Hesitant fuzzy, Higher education institutions, SWARA

1 Introduction

Accelerated innovation in digital technologies (DT) has had a remarkable impact on institutions, significantly influencing business models, corporate strategies, organizational culture, operational processes, and the required skillset [16, 45]. In this environment, many entities heavily invest in digital infrastructure and augment digital adoption by integrating relevant DT to sustain competitiveness [59]. Higher education institutions (HEI) are no exception. The increasing reliance on DT across the globe has profoundly affected how HEI provide education, conduct research and manage governance issues. The Covid-19 pandemic has further forced HEI to incorporate digitalization into their activities, ranging from setting up online learning platforms to data-driven assessment, decision making and remote collaboration [1, 51].

With the rapid advancement of digitalization, assessing digital maturity (DM) has become increasingly important for HEI [38]. DM reflects the degree to which HEI leverage DT to enhance its educational and operational processes, improve user experiences and create innovative service offerings. While digital transformation holds significant importance in higher education, there is no clear consensus on its outcomes and the management strategies that should be adopted [34]. The changes brought by digitalization in teaching and learning necessitate a multi-system approach. This includes investing in infrastructure, enhancing the competencies of academics, updating curricula, revising assessment methods, promoting open content, and strengthening quality control measures [18]. Therefore, integrating DT into higher education should be handled carefully, including technological, pedagogical, and organisational dimensions. Implementing a DM measurement framework for HEI can assist in evaluating their DM level, pinpointing areas of improvement, and leveraging digital tools to strengthen their positioning.

Although many studies have predominantly focused on the acceptance, progression, and technical aspects of digitalization, relatively few of them have explored the assessment of DM level in HEI [17, 18, 39, 51]. Consequently, there is a need to develop DM measurement models tailored to digital transformation in HEI. Universities invest substantially in information and communications technology (ICT) to transition into fully digital institutions. However, this should be executed in an integrated manner to ensure that academic and administrative staff, students, and other stakeholders receive the maximum benefits.

This study aims to develop a DM measurement model for HEI. By involving academic and administrative staff and students from a selected foundation university in Eastern Europe, the research proposes a framework to help HEI prioritize their specific goals and address unique challenges in digital transformation. We first interview the academic and administrative units to understand their perceptions of digitalization. Following these interviews, we run a survey to them and students to gather feedback on the proposed DM model's six main and 24 sub-dimensions. We collected a total of 212 responses. The fuzzy SWARA method is then employed to analyze the participants' feedback and assess the DM level of the university based on the proposed model.

Recognizing the important role of higher education in a knowledge and information-based society, this study makes three main contributions. First, it introduces a multi-dimensional model for assessing the DM level of HEI, addressing a critical gap in the literature. Unlike prior studies that primarily emphasize technical infrastructure and specific dimensions, this model offers a holistic evaluation by incorporating input from all stakeholders across the HEI. Second, this research offers valuable insights for the stakeholders of higher education. By assessing DM, it facilitates the setting of forward-looking goals for HEI, identifies areas that require digital improvement, and promotes educational advancement. Finally, this study addresses a challenge beyond simply measuring DM. HEI face a practical governance problem: while everyone agrees on the importance of digital transformation, institutional leaders lack systematic tools to assess where they stand and could track their progress, and decide how to allocate limited budgets across multiple digitalization needs [8, 24, 41]. Digital maturity models developed for businesses do not fit universities as higher education has unique characteristics: HEI must balance teaching and research missions, academic freedom must be respected, and different stakeholder groups, i.e. academics, administrative staff, students, often have competing priorities for digitalization [25, 47].

The proposed framework can be applied in different socio-economic settings where there is varying levels of digital infrastructure [23]. The weighting system of the SWARA approach enables HEI to re-weight the dimensions based on their requirements and resource availability [46, 52]. For instance, HEI operating in resource-restricted settings may assign more importance to digital infrastructure and human resources than to research digitalization. Moreover, the five-level maturity model (Basic to e-Mature) enables relative assessments that can be performed in a context-specific manner, ensuring that the framework can be implemented in different higher education systems with varying socioeconomic backgrounds. Additionally, the proposed framework can be applied for longitudinal assessment to help HEI measure the 24 sub-dimensions periodically in compliance with their long-term strategic plan for assessing their progress and taking proactive actions in shaping future prospect.

Building to these points, the research questions (RQs) in the present study are formulated as follows:

RQ1: What are the critical dimensions and sub-dimensions that constitute digital maturity in higher education institutions, as perceived by multiple stakeholder groups?

RQ2: How do these dimensions differ in their relative importance and performance levels, and what strategic priority areas for digital transformation do these differences influence?

RQ3: To what extent does the proposed multi-criteria framework maintain its methodological robustness under different fuzzy approaches?

2 Literature review

Digital maturity represents the extent to which DT is integrated into business models [59]. According to Chainas and Hess [11], DM shows the performance of transformation efforts and how the institutions systematically plan to adapt to an increasingly digital landscape. In this context, DM models serve as frameworks that guide digital transformation processes, focusing on the key dimensions that should be evaluated to attain a higher level of DM [9, 53].

DM models in HEI help universities assess their digital competencies and make strategic improvements to enhance educational offerings and operational efficiency. Although the structure and focus of these models may vary, they usually seek to integrate DT into managerial, educational and operational processes. An in-depth examination of DM models across sectors highlights significant similarities in key dimensions. Most of these models focus on essential areas, i.e. management and leadership, technology and infrastructure, strategy, and organizational culture [27, 31, 40, 44, 48, 58]. The primary goal of the business-focused models is to enable entities to gain a competitive advantage through digitalization of their processes [22, 29], while models in the education sector aim to assess the digitalization level to enhance the quality of educational processes and research outcomes [21, 26, 30].

A review of models in the education sector indicates that their key dimensions typically include the use of digital tools, pedagogical integration, student-centered learning

Table 1 Comparative dimensions of the leading digital maturity models for higher education

	Model	Authors	Focus area	Dimensions	Digitalization levels
1	DigCompOrg Model (European Commission Framework)	Kampylis, Punie and Devine [30]	Primary and secondary schools, HEI	Leadership & Governance Practices; Teaching and Learning Practices; Professional Development; Assessment Practices; Content and Curricula; Collaboration and Networking; Infrastructure	Not specified
2	DMFHEI Model	Durek, Kadoic and Redep [18]	HEI	Leadership, Planning and Management; Quality Assurance; Scientific Research; Technology Transfer and Service to Society; Learning and Teaching; ICT Culture; ICT Resources and Infrastructure	Basic Initial e-Enabled e-Confident e-Mature
3	Goal oriented project planning model	[1]	HEI	Leadership, Planning and Management; Quality Assurance; Scientific Research; Digital Learning and Teaching; Community Service; Equipment and Technological Infrastructure; Technological Culture	Basic Initial e-Enabled e-Confident e-Mature
4	HEInnovate (OECD and EC Collaboration)	Hofer and Kaffka [26]	HEI	Leadership and Governance; Organisational Capacity, Funding, & Incentives; Entrepreneurial Teaching and Learning; Preparing and Supporting Entrepreneurs; Digital Transformation and Capability; Knowledge Exchange and Collaboration; The Internationalized Institution; Measuring Impact	Not specified
5	UniDigMaturity	Doneva, Gaftandzhieva, and Totkov [17]	HEI	Policy for quality assurance; Design and approval of programmes; Student-centred learning, teaching and assessment; Student admission, progression, recognition and certification; Teaching staff; Learning resources and student support; Information management; Public information; On-going monitoring and periodic review of programmes; Cyclical external quality assurance	Not specified
6	A theoretical model for digital transformation at the Autonomous University of Chile	Acuna, Hernandez-Perlines and Cisneros [2]	HEI	Institutional strategic framework focused on digital transformation; Digital culture, organization and structure; Critical capabilities and key resources; Student life cycle value; Ecosystem; Flexible and personalized teaching; Points of contact with students; Social networks and profile research; Teaching transformation processes for higher education; Investment in information technology	Phase 1: Availability of digital resources Phase 2: Utilization of digital resources Phase 3: Integration of technological platforms
7	Digital Maturity Index	Von der Heyde [57]	HEI	Reliability; Usability; Flexibility; Standardization; Security; Scalability; Integration; Continuous Improvement; Performance; Automation	Not specified
8	MD4U Model	Martínez, Largo, and Carmona [40]	HEI	Digital culture; Business Availability; New Services; Interaction with Students; Quality and Competitive Training; Knowledge for Decision Making; Strategic Vision of the University	Not specified

Table 1 (continued)

	Model	Authors	Focus area	Dimensions	Digitalization levels
9	MMEO Model	Ifenthaler and Egloffstein [27]	HEI	Infrastructure; Strategy and Leadership; Organization; Employees; Culture and Educational Technology	Digitally Minimalist Digitally Conservative Digitally Pragmatist Digitally Advanced Digitally Trailblazing
10	Digital Maturity Index (Times Higher Education)	Lee et al. [36]	HEIs	Strategy; People and Culture; Technology, Data; Utilization	Incidental Intentional Integrated Optimized
11	The Proposed Framework			Management and Leadership (Digitalization Investment, Financial Management, Leadership and Decision-Making Methods, Strategic Planning, Process Management); Digital Infrastructure (Information Management Systems, Documentation and Archiving, Internet Infrastructure, Cybersecurity, Technological Equipment); Learning and Teaching Applications (Online Education, Student Admission, Learning Process, and Graduation, Learning Resources and Access, Assessment and Evaluation Methods); Digitalization and Innovation in Research (Use of Digital Resources in Research, Access to Databases and Online Resources);Communication and Collaborations (Collaborations with Industry, Academic, and Other Institutions, Internal Communication, Student Information, Website); Human Resources (Digital Skills, Recruitment, Performance Development and Evaluation)	Basic Initial E-Enabled E-Confident E-Mature

and teacher training [3, 7, 21]. Models designed explicitly for HEI cover general dimensions such as digital teaching and learning and student engagement, while also placing significant emphasis on scientific research, innovation, and collaboration [10, 18, 40]. Table 1 presents the leading models for measuring digitalization in HEI. The following part briefly outlines the key features of each model.

The DigCompOrg model, developed by the European Commission (EC), assesses the digital competencies of the educational institutions, including primary and secondary schools and HEI [30]. It measures the critical dimensions to digitalization such as leadership and governance, teaching and learning practices, professional development, assessment practices, content and curricula, collaboration and networking, and infrastructure. The DMFHEI model, developed by Đurek et al. [18], examines planning and management, quality assurance, scientific research, technology transfer and service to society, besides the dimensions covered in the previous model. The HEInnovate model, developed by Hofer and Kaffka [26] in collaboration with the OECD and EC, primarily concentrates on measuring the impact of innovation and digital transformation in universities. The Digital Maturity Index, developed by Von der Heyde [57], assesses the capabilities of the systems' technical infrastructure, mainly emphasizing the dimensions of reliability, usability, flexibility, standardization, security, scalability, integration, continuous improvement, performance and automation. Finally, MD4U model developed by Martínez et al. [40] and implemented in Spanish universities, considers digital culture, business availability, new services, interaction with students, quality and competitive training, knowledge and decision making, and strategic vision of the university as the key areas of digital transformation. The main dimensions are the capacity to create new processes and redefine strategic functions.

Besides these models, some frameworks have not been extensively tested. Rossman [44] suggests a DM model comprising eight competency dimensions pertaining to strategy, leadership, business and operating model, people, culture, governance, and technology. Shindina et al. [49] indicate the main areas in assessing the DM of HEI, i.e. digital ICT, digital teaching and assessment methods, digital research capabilities, digital campus facilities, paperless environment, digital administrative functions, and digital management. According to Tocto-Cano et al. [55], the maturity models for higher education can be categorized into nine groups: models oriented towards teaching, ICT, student monitoring, intellectual capital, e-learning, university entrepreneurship, employability of grades, strategic planning of universities, and IT governance.

The development of digital capabilities can contribute to higher DM. However, there is no commonly accepted framework for measuring DM in HEI. The DM models for universities are still in their infancy. Some models focus on teaching and learning, management and research, highlighting the need for an integrated model encompassing entire institution, while others mainly concentrate on information system management [5]. Many models do not cover critical aspects such as cybersecurity and data protection.

From this perspective, survey studies, systematic reviews, and bibliometric analyses addressing DM, technological transformation, and digital transition have identified several areas that remain underexplored. The global transition toward the digital university paradigm has catalyzed a fundamental restructuring of HEI, yet a significant disparity remains between the adoption of educational technologies and the strategic integration of comprehensive digital frameworks. While bibliometric studies [6, 12, 35] emphasize the necessity of fostering digital competencies, i.e. spanning technological, informational, multimedia, and communicative dimensions, much of the existing works remains siloed within pedagogical innovations such as virtual laboratories, augmented reality, and adaptive learning platforms. A critical gap exists in the holistic transformation of institutional processes and administrative digital services. While tools for student performance and learning analytics mature, the digitalization of core organizational workflows remains under-investigated. Although many empirical studies have used the widely accepted Technology Acceptance Model (TAM) [14], the Unified Theory of Acceptance and Use of Technology (UTAUT) [56], and the DeLone and McLean Success Model [15] to measure system efficacy, there is a lack of rigorous, standardized indicators to assess DM across different institutional levels. Consequently, there is a need for research that bridges these gaps by developing integrated models to ensure that digital university functions effectively as a cohesive educational ecosystem [37, 42, 50].

Systematic review of existing DM models for HEI identifies three key gaps that are addressed in this study. First, there is a lack of stakeholder-weighted prioritization in existing models. They are descriptive in terms of maturity levels, but do not have a systematic approach to integrate multi-stakeholder views in determining dimension weights and priorities. Second, most of these models focus on either infrastructure [57], educational processes [30], or entrepreneurship [26], but they do not have a comprehensive integration of managerial, educational, research, infrastructure, and human resource dimensions in a single weighted framework. The proposed model enables a comprehensive assessment of DM through six main dimensions and 24 sub-dimensions that allow for an in-depth examination of each component. This study addresses the lack of a standardized framework for measuring DM in HEI by developing an integrated model that evaluates DM across the entire institution. In this sense, it provides a holistic tool to support HEI in advancing their capabilities and achieving a higher DM level. Finally, most of the models do not employ rigorous quantitative weighting techniques, but they use expert opinions or equal weighting without utilizing multi-criteria decision-making techniques. The present study fills this gap by combining qualitative dimension identification with Picture Fuzzy SWARA-based prioritization, thereby linking diagnosis with actionable governance insights.

Table 1 show how the proposed framework positions itself relative to existing approaches.

3 Data and methodology

In this study, we developed a comprehensive framework to assess the DM level of universities by incorporating stakeholder perspectives. Using a case study approach, we developed our model based on a foundation university located in Eastern Europe. The research design follows four sequential phases: (i) Dimension identification, (ii) Stakeholder assessment, (iii) Dimension weighting and modelling, and (iv) Robustness and comparative analysis. Each phase builds upon the outputs of the previous stage to ensure conceptual and analytical consistency. We employed a holistic approach by integrating qualitative and quantitative methods. Figure 1 illustrates the whole research process, and the subsequent section provides detailed information for each step. This research involving human participants, human material, or human data, has been performed in

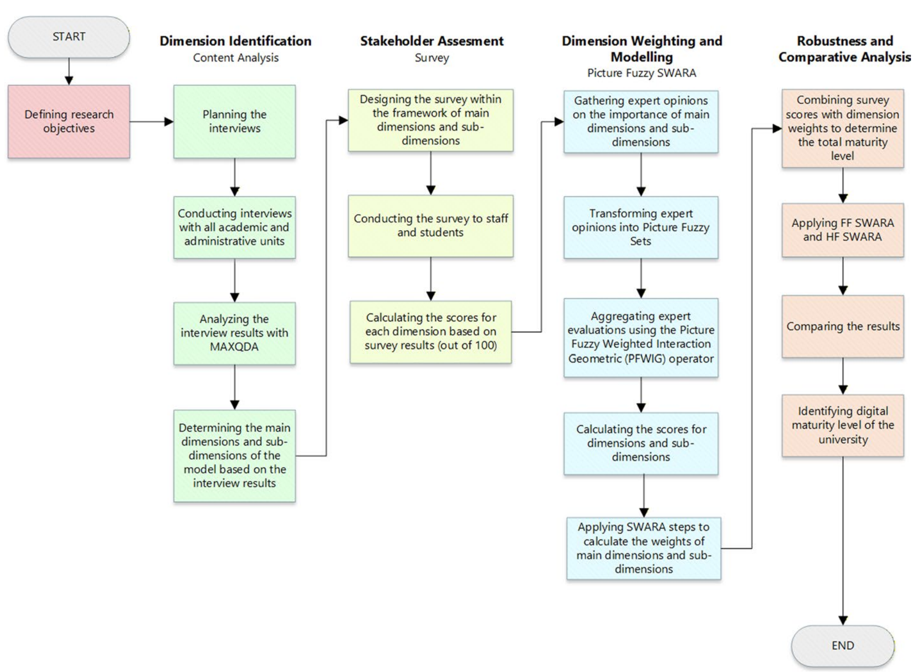

Fig. 1 The steps of the research methodology

accordance with the Declarations of Helsinki and approved by an appropriate ethics committee. The name of the ethics committee is Ibn Haldun University Ethics Committee Board for Social Sciences and Humanitites Research and Publication Ethics and the reference number is 2023/07-01. All the participants have provided informed consent at the beginning of the online form shared with them through Google Forms.

3.1 Dimension identification

This phase combined qualitative interviews and content analysis to systematically identify and refine the dimensions of the digital maturity. We conducted 32 interviews with the representatives of the academic and administrative units in the university. We mainly covered digital infrastructure, digital skills, integration of DT, and strategic planning in the interviews. We also explored the key matters related to digital tools, online platforms, and strategies for improving digital competencies. We analysed the data using MAXQDA 2020 software. We identified and categorized themes based on their recurring patterns, forming the ground for the subsequent survey design. The interviews provided critical inputs for defining the principal dimensions and sub-dimensions of the DM in the university.

3.2 Stakeholder assessment

In this phase, the dimensions identified in Phase 1 were operationalized into measurable survey items to capture stakeholder evaluations of digital maturity. Based on the dimensions in Phase 1, a structured survey instrument was developed. The survey included 124 items organized into six main dimensions and 24 sub-dimensions as presented in Fig. 2. It covered digital infrastructure, management and leadership, learning and teaching applications, innovation in research, communication and collaborations, and human

Fig. 2 The main dimensions and sub-dimensions of the survey

resources. We run the survey among the academic and administrative staff and students to obtain their evaluations of DM. 212 participants responded to the survey, comprising 58 academic and 76 administrative staff, and 78 students.

The interviews in Phase 1 were conducted with authorized academic and administrative representatives who hold managerial or coordinative responsibilities related to digital processes within the university. In this phase, we followed a purposive sampling strategy to ensure informed, institution-level insights during the dimension identification stage.

In contrast, the survey in Phase 2 was distributed institution-wide to all academic and administrative staff, and students through the university's official communication channels. Participation was voluntary and open to the entire university community. Therefore, the survey sample was formed through broad institutional outreach rather than selective targeting. The interviews were exploratory and formative, while the survey aimed to capture wider stakeholder perceptions. Furthermore, the weighting of the dimensions was performed independently by an expert panel using the Stepwise Weight Assessment Ratio Analysis (SWARA) method, minimizing the potential impact of any overlapping results of the participants on the final aggregated results.

3.3 Dimension weighting and modelling

While the first two phases focused on identifying the dimensions of DM and capturing stakeholder evaluations, this phase introduces a structured quantitative weighting mechanism under uncertainty. To determine the relative importance of the identified dimensions and sub-dimensions, the SWARA method was extended using Picture Fuzzy Sets (PFSs), allowing expert judgments to be modelled with greater flexibility and precision.

3.3.1 Expert evaluation and PFSs Transformation

To determine the relative importance of each dimension, we employed the Stepwise Weight Assessment Ratio Analysis (SWARA) method introduced by Kersuliene et al. [33]. This approach is considered an innovative solution for situations where existing Multi-Criteria Decision-Making (MCDM) methods cannot determine weights directly based on the relative importance of criteria. SWARA assigns the highest priority to the most significant criterion while placing the least critical one at the lowest level. The participation of experts plays a vital role in this process, as their judgments are systematically incorporated into the weight allocation procedure [43].

This study used Picture Fuzzy Sets (PFSs) to capture better the uncertainties involved in expert assessments. In simple terms, fuzzy logic enables us to describe situations that are not just "yes or no" but fall somewhere in between. For instance, instead of classifying a dimension only as "important" or "not important", fuzzy methods allow more nuanced judgments such as "partly important" or "somewhat unimportant". This makes it possible to move beyond rigid classifications and acknowledge the shades of importance naturally occurring in human judgment. Picture fuzzy sets extend this principle even further by introducing three levels of judgment—membership (agreement), non-membership (disagreement), and neutral membership (undecided)—along with a refusal degree that reflects hesitation or lack of information. This flexible structure provides a more realistic representation of human judgment, which is especially valuable in higher education management systems where decisions are rarely black and white. On this respect, PFSs differ from intuitionistic fuzzy sets by distinguishing a consciously neutral position from a lack of knowledge. Neutrality may reflect an intentional evaluative stance—where an expert neither supports nor opposes a dimension—rather than simple informational uncertainty. In higher education context, such neutrality may arise when a criterion is perceived as context-dependent. Separating this from refusal may allow a more nuanced interpretation of expert judgments. In practical terms, this means that university administrators can explicitly indicate when they neither support nor oppose the importance of a dimension, rather than being forced into an agreement or disagreement. This improves the realism of institutional evaluations.

The evaluation process involved a panel of 10 experts, carefully selected based on their expertise in the field. They rated each dimension and sub-dimension on a five-point linguistic scale ranging from very unimportant (1) to very important (5). These evaluations were then transformed into PFSs, represented by the membership (ψ), neutral membership (θ), and non-membership (ϑ) degrees, satisfying the condition $\psi + \theta + \vartheta \leq 1$. The refusal degree (ι) was calculated as $\iota = 1 - \psi - \theta - \vartheta$ [13]. To operationalize expert judgments, linguistic importance levels were transformed into PFSs. This transformation ensures that qualitative expert perceptions can be systematically incorporated into the quantitative weighting process without losing the nuance of subjective evaluation.

The triadic structure of PFSs—capturing membership, neutral membership, and non-membership degrees—offers a more comprehensive reflection of human decision-making than traditional fuzzy or intuitionistic fuzzy sets [20]. The mapping of linguistic terms into PFSs values used in this study is provided in Table 2.

3.3.2 Aggregation of the expert assessments and score calculation

Since multiple experts participated in the evaluation, their individual judgments were aggregated to obtain a collective weighting structure. This aggregation ensures that the final weights reflect group consensus rather than individual bias. We applied the Picture Fuzzy Weighted Interaction Geometric (PFWIG) operator to aggregate the fuzzy evaluations. Let $\alpha_i = (\psi_i, \theta_i, \vartheta i)$ represent the set of Picture Fuzzy Numbers (PFNs), and w_i represent the corresponding weights. The PFWIG operator is defined in Eq. 1 [28]:

$$\begin{aligned} &\mathrm{PFWIG}\left(\alpha 1, \alpha 2, \ldots, \alpha \mathrm{n}\right) = \Big(\prod\nolimits_{i=1}^{\mathrm{n}} \left(1 - \theta_{\mathrm{i}} - \vartheta_{\mathrm{i}}\right)^{\mathrm{w_i}} - \prod\nolimits_{i=1}^{\mathrm{n}} \left(1 - \psi_{\mathrm{i}} - \theta_{\mathrm{i}} - \vartheta_{\mathrm{i}}\right)^{\mathrm{w_I}}, \\ &, \prod\nolimits_{i=1}^{\mathrm{n}} \left(1 - \vartheta_{\mathrm{i}}\right)^{\mathrm{w_i}} - \prod\nolimits_{i=1}^{\mathrm{n}} \left(1 - \theta_{\mathrm{i}} - \vartheta_{\mathrm{i}}\right)^{\mathrm{w_i}}, \\ &1 - \prod\nolimits_{i=1}^{\mathrm{n}} \left(1 - \vartheta_{\mathrm{i}}\right)^{\mathrm{w_i}}\Big) \end{aligned} \tag{1}$$

After aggregating the fuzzy evaluations using the PFWIG operator, we calculated the score values of the PFNs as follows [54]:

Table 2 Conservation between the linguistic terms and PFSs

Criterion Evaluation Terms	Mark	PFSs Values
Very important	VI	(0.9, 0, 0.1)
Medium important	MI	(0.7, 0.1, 0.2)
Medium	M	(0.5, 0.1, 0.1)
Medium unimportant	MU	(0.5, 0.2, 0.2)
Very unimportant	VU	(0.1, 0.4, 0.4)

$$\frac{S(\alpha) = 2 + \psi - \theta - \vartheta}{3}, \text{and } \mathrm{S}(\alpha) \in [0,1] \tag{2}$$

We ranked the scores for each dimension to identify the highest and lowest priority areas.

3.3.3 SWARA steps for the weight calculation

The SWARA method determines the weights through a stepwise comparative process. First, experts rank the dimensions in order of importance and then specify how much less important each subsequent dimension is compared to the previous one. This sequential logic enables a structured and transparent derivation of relative weights. To determine the weights of the dimensions, we used the following SWARA steps [33].

(1) Each dimension's comparative importance *(c_j)* was calculated as the score difference between the consecutive ranked dimensions.

(2) The coefficient *(k_j)* for each dimension was determined as:

$$k_j = \begin{cases} 1, j = 1 \\ c_j + 1, j \geq 2 \end{cases} \tag{3}$$

(3) The recalculated weights *(d_j)* were computed iteratively as:

$$d_j = \begin{cases} 1, j = 1 \\ \frac{d_{j-1}}{k_j}, j \geq 2 \end{cases} \tag{4}$$

(4) Finally, the normalized weights *(w_j)* were obtained using the formula:

$$w_j^s = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{5}$$

The calculated weights were normalized to ensure comparability across all dimensions (Eq. 5). Normalization guarantees that the total weight equals one, allowing each dimension to proportionally contribute to the overall digital maturity score.

Overall, the Picture Fuzzy SWARA framework provides a rational and transparent mechanism for determining the relative importance of digital maturity dimensions under uncertainty. By integrating structured expert comparison with fuzzy uncertainty modelling, this approach strengthens the validity of the proposed digital maturity model and supports consensus-based institutional assessment.

3.4 Robustness and comparative analysis

This phase evaluates the stability of the weighting results through cross-method comparison and integrates the expert weights with stakeholder survey scores. The aim is to ensure methodological robustness, compute the digital maturity score, and classify this score into predefined digital maturity levels to enhance interpretability.

3.4.1 Integration and cross-method analysis

In this stage, the derived weights were integrated with the survey results to calculate the weighted scores for each dimension. These scores were then used to construct the digital maturity model, providing a comprehensive framework for assessing the university's DM level. Furthermore, the methodology was extended to utilize Fermatean Fuzzy Numbers (FFNs) and Hesitant Fuzzy Numbers (HFNs) within the SWARA framework. The results obtained through these methods were compared with those derived from the Picture Fuzzy SWARA approach. This comparative analysis aims to evaluate each method's effectiveness and robustness in determining the weights. The analysis showed the consistency of the results across the methods, while showcasing unique strengths in handling uncertainty. The FFNs and HFNs provided alternative views, offering additional insights into the assessment process.

3.4.2 Digital maturity level classification framework

We used a framework to assess DM level based on the scores derived from the prior steps. In line with previous studies [1, 18], the DM levels were classified into five categories: Basic, Initial, e-Enabled, e-Confident, and e-Mature. Each category corresponds to a score range with equal intervals based on a 100-point scale, ensuring a systematic and measurable approach to assessing the DM.

4 Empirical findings

4.1 The results of the interviews

The results of the interviews revealed a total of 85 unique codes, repeated 516 times across the dataset. The most frequently mentioned themes were the use of digital archive systems (5.4%), integration of information systems (5.0%), and digital competency training (5.0%). The additional topics were the resources allocated to digital projects (3.5%), automation of business processes (3.3%), and the use of artificial intelligence tools (3.3%). Tables 3 and 4 present the results of the interviews held with academic and administrative units, respectively.

The themes with lower frequencies included implementing cybersecurity policies, using data analytics, digital process traceability, and the adequacy of distance education platforms. These findings provide insights into the current digital transformation in the university, highlighting the strengths and potential areas for improvement. Overall, the survey results indicate moderate to high performance across most of the dimensions. A more detailed, weighted, and normalized analysis is provided in Sect. 4.5.

4.2 The findings of the survey

The survey results in Table 5 and Fig. 3 provide the scores out of 100 for each main dimension and its sub-dimensions, reflecting the respondents' perceptions. The findings

Table 3 Top 10 most frequently mentioned themes in the interviews with academic units

Code	Frequency	Percentage
Integration of information systems	9	5.4%
Integration of digital tools into classroom education	9	5.4%
Use of artificial intelligence tools	8	4.8%
Training academics on digital applications	7	4.2%
Use of data visualization tools	6	3.6%
Use of digital tools for exams and assessments	6	3.6%
Resources allocated for digital projects	6	3.6%
Forms that can be electronically processed	5	3.0%
Implementation of cybersecurity policies	5	3.0%
University's vision for digital transformation	4	2.4%

Table 4 Top 10 most frequently mentioned themes in the interviews with administrative units

Code	Frequency	Percentage
Use of digital archiving systems	14	5.7%
Digital competency training and development	14	5.7%
University's vision for digital transformation	11	4.5%
Forms that can be electronically processed	10	4.1%
Resources allocated for digital projects	9	3.7%
Integration of information systems	9	3.7%
Digital official correspondence	9	3.7%
Digital process traceability	7	2.9%
Process improvement through digital Technologies	7	2.9%
Difficulty in learning new Technologies	7	2.9%

Table 5 The scores of the main dimensions of digital maturity

Main Dimension	Score out of 100
MD 1- Management and Leadership	69,02
MD 2- Digital Infrastructure	70,92
MD 3- Learning and Teaching Applications	72,66
MD 4- Digitalization and Innovation in Research	75,47
MD 5- Communication and Collaborations	70,73
MD 6- Human Resources	70,57

Main Dimension	Weight	Sub-Dimension	Local Weight	Global Weight	Survey Score of the Sub-Dimension	Weighted Score
MD1 - Management and Leadership	0,173	SD1 - Digitalization Investment	0,202	0,0351	70,31	2,466
		SD2 - Financial Management	0,196	0,034	64,13	2,182
		SD3 - Leadership and Decision-Making Methods	0,198	0,0344	73,97	2,543
		SD4 - Strategic Planning	0,202	0,0351	78,47	2,754
		SD5 - Process Management	0,201	0,0348	64,32	2,24
MD2 - Digital Infrastructure	0,173	SD6 - Information Management Systems (ERP, etc.)	0,202	0,035	68,86	2,408
		SD7 - Documentation and Archiving	0,192	0,0332	71,19	2,367
		SD8 - Internet Infrastructure	0,203	0,0352	71,63	2,523
		SD9 - Cybersecurity	0,204	0,0354	70,21	2,488
		SD10 - Technological Equipment	0,199	0,0345	72,9	2,517
MD3 - Learning and Teaching Applications	0,17	SD11 - Curricula and Course Content	0,2	0,0338	71,84	2,431
		SD12 - Online Education	0,207	0,0351	71,13	2,5
		SD13 - Student Admission, Learning Process, and Graduation	0,192	0,0326	70,02	2,28
		SD14 - Learning Resources and Access	0,203	0,0344	77,79	2,679
		SD15 - Assessment and Evaluation Methods	0,198	0,0336	75,22	2,526
MD4 - Digitalization and Innovation in Research	0,172	SD16 - Use of Digital Resources in Research	0,508	0,0875	76,49	6,691
		SD17 - Access to Databases and Online Resources	0,492	0,0846	72,77	6,158
MD5 - Communication and Collaborations	0,156	SD18 - Collaborations with Industry, Academic, and Other Institutions	0,245	0,0382	71,06	2,716
		SD19 - Internal Communication	0,251	0,0391	69,98	2,738
		SD20 - Student Information	0,253	0,0395	71,62	2,826
		SD21 - Website	0,25	0,0389	70,64	2,751
MD6 - Human Resources	0,156	SD22 - Digital Skills (Staff)	0,347	0,054	73,65	3,978
		SD23 - Recruitment	0,311	0,0484	65,16	3,155
		SD24 - Performance Development and Evaluation	0,342	0,0533	62,66	3,342
Overall Score						**71,26**

Fig. 3 The fuzzy weights of the dimensions

indicate that digitalization and innovation in research are the strongest dimensions, scoring 75.47. The effective utilization of digital resources (76.49), including access provision to databases for research processes (72.77), has contributed to this success. This result aligns with the findings of the prior studies [1]. The learning and teaching dimension ranks second with a score of 72.66. Notably, the learning resources and access dimension, scoring 77.79, highlights the diversity and accessibility of resources provided by the university to academics and students. This result corroborates the findings of the prior studies [18, 30]. Areas such as student admission, learning process, and graduation (70.02) require further enhancement. Additionally, the university should improve its online education system (71.13). Digital infrastructure ranks third with a score of 70.92, with the technological hardware dimension (72.90) reflecting the university's investment in digitalization.

However, cybersecurity (70.21) and internet infrastructure (71.63) highlight the need for improvement in infrastructure security and internet services. This result aligns with the findings of Aliyu et al. [4] and Durek [19]. In particular, the score of 68.86 in information management systems shows significant deficiencies in the inter-departmental communication system, which is quite important for the execution of digital operations. Similarly, documentation and archiving (71.19) require further enhancement. These shortcomings spotlight the absence of an efficient management information system at the university—the communication and collaboration dimension scores being at an average of 70.7. While collaborations with industry and academia (71.06) are satisfactory, internal communication (69.98) shows room for improvement. Lastly, the university website (70.64) requires further enhancement.

4.3 The weighting of the dimensions

The evaluation of the main and sub-dimensions was carried out by the experts (E_1-E_{10}) using the linguistic terms and their corresponding Picture Fuzzy Sets values given in Table 2. To extract the weights of the dimensions, we applied the SWARA steps. Each dimension's comparative importance (c_j) was calculated as the score difference between the consecutively ranked dimensions. The coefficient (k_j) for each dimension was determined using the formula in Eq. (3). The recalculated weights (d_j) were computed iteratively as shown in Eq. (4). Finally, the normalized weights (w_j) were obtained using Eq. (5).

As presented in Table 5, the scores of the main dimensions of DM indicate the university's performance across the six core areas of the framework. The local weights (representing the weights of the sub-dimensions within the respective dimensions) and global weights (representing the weights of the sub-dimensions across all dimensions), derived from the SWARA analysis, are shown in Fig. 3. These weights provide a hierarchical view of the DM framework, enabling the prioritization of the areas for improvement based on their overall impact in the DM. The overall digitalization score of the university is 71.26. With this score, the DM level of the university is classified as e-Confident.

4.4 Comparison of the Picture fuzzy, Fermatean fuzzy, and Hesitant fuzzy results

We compared the results of the Picture Fuzzy (PF) SWARA with the results obtained by using Fermatean Fuzzy (FF) and Hesitant Fuzzy (HF) methods to ensure robustness. These comparative analyses evaluated the consistency of the results across different fuzzy frameworks, while highlighting the unique capabilities of each of them in addressing uncertainty and hesitation in decision-making. Figure 4 compares the scores for the main dimensions (MD1–MD6) across the three methods. The results show a high degree of consistency. Figure 5 compares the sub-dimension weights derived from PF-SWARA, FF-SWARA, and HF-SWARA methods. While PF-SWARA showed weight stability, FF and HF approaches provided additional flexibility in addressing uncertainties, particularly in dimensions with closely ranked sub-dimensions.

The global weights and the corresponding weighted scores for each sub-dimension show a high degree of consistency across the methods, indicating the robustness of the

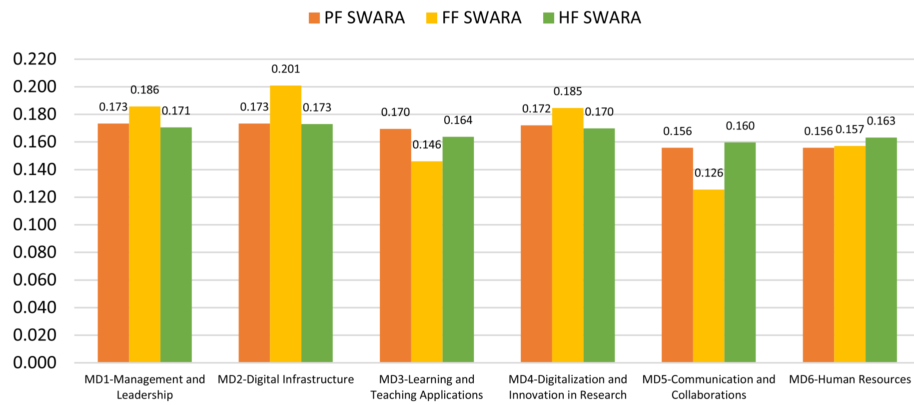

Fig. 4 The comparison of the main dimensions' weights across the PF SWARA, FF SWARA, and HF SWARA methods

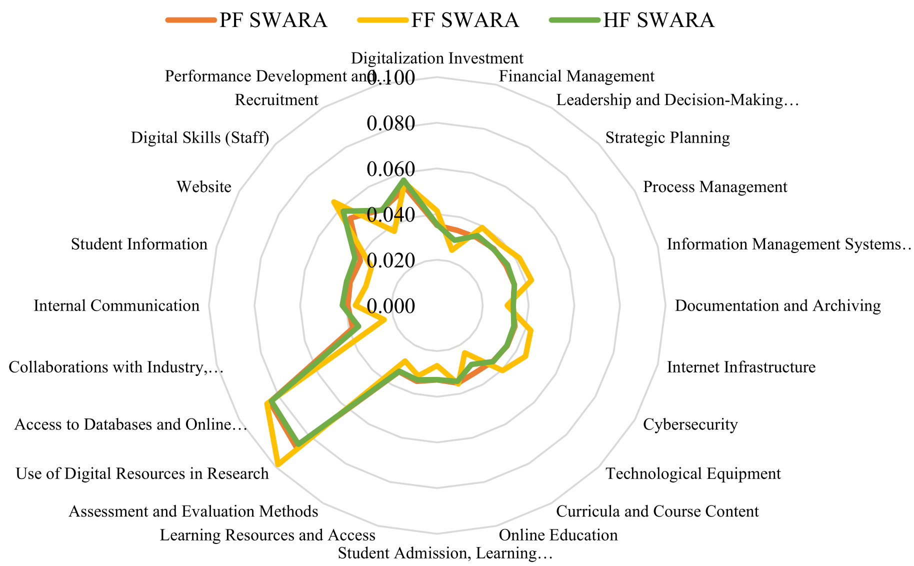

Fig. 5 The comparison of the sub-dimensions' weights across the PF SWARA, FF SWARA, and HF SWARA methods

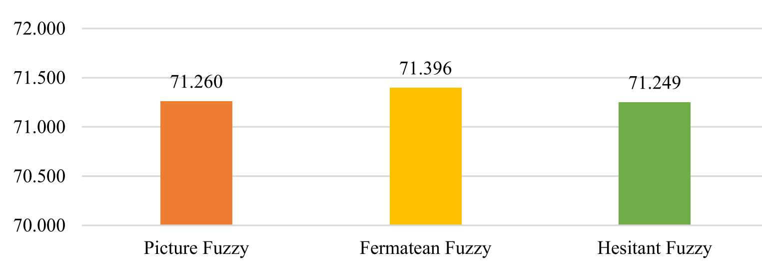

Fig. 6 The digital maturity levels of the different fuzzy evaluation methods

evaluation process. While there are minor variations in specific sub-dimension scores—likely due to the unique properties of each fuzzy approach—the overall results are closely aligned. The DM levels that fall within a narrow range of 71.249 to 71.396 further confirm this consistency as shown in Fig. 6. These findings suggest that all fuzzy evaluation methods effectively capture the relative importance and contribution of the sub-dimensions to the DM model of the university.

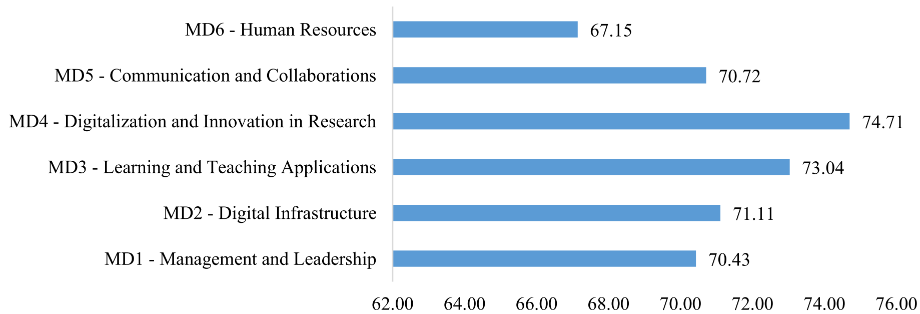

Fig. 7 Normalized scores of the main dimensions in digital maturity assessment

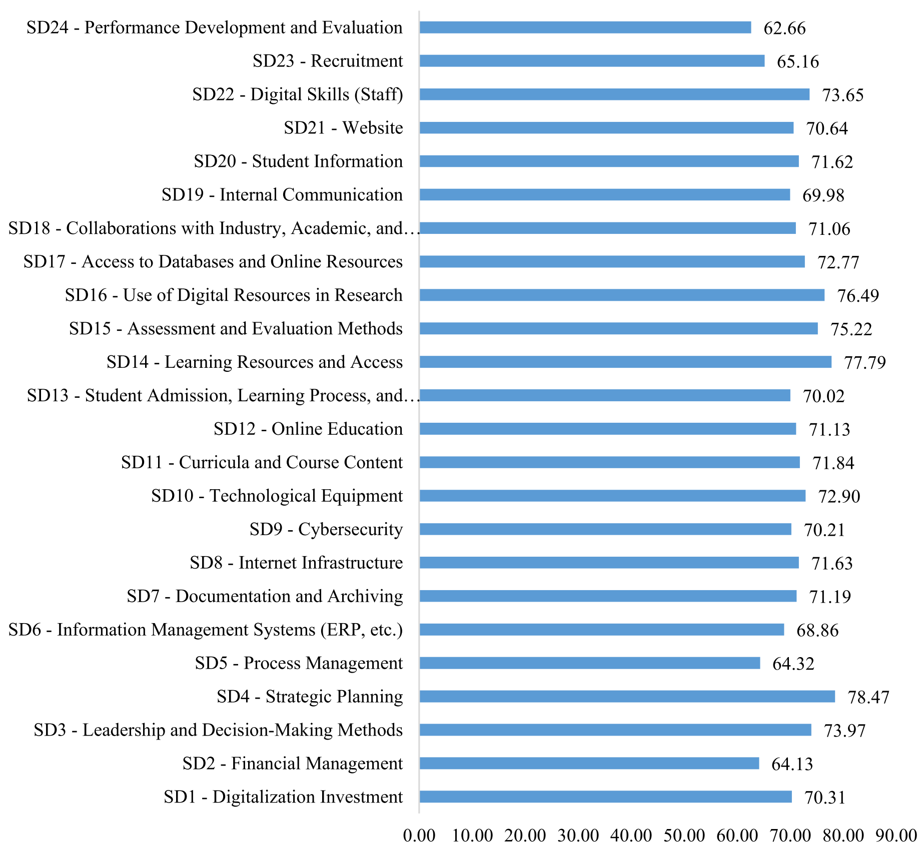

Fig. 8 Normalized scores of the sub-dimensions in digital maturity assessment

4.5 The analysis of the results for the main and sub-dimensions

The weighted scores for the main and sub-dimensions derived using the Picture Fuzzy SWARA method have been normalized to a 100-point scale. This normalization facilitates a more transparent and more interpretable representation of the university's DM, offering valuable insights for identifying the strong points and weak areas for improvement. These findings help guide the strategic digital transformation efforts of HEI. Figure 7 presents the normalized scores of the six main dimensions, highlighting their aggregated performance, while Fig. 8 displays the normalized scores of the sub-dimensions. Among these dimensions, MD4—Digitalization and Innovation in Research achieved the highest score of 74.71. This result underscores the institution's strong focus on integrating digital tools to foster research and innovation. Supporting this dimension, the sub-dimensions of SD16—Use of Digital Resources in Research (76.49) and SD17—Access to Databases and Online Resources (72.77) indicate the effective utilization of technological resources in academic inquiries.

The second-highest score (73.04) was observed for MD3—Learning and Teaching Applications, reflecting significant progress in modernizing educational practices. The sub-dimensions of SD14—Learning Resources and Access (77.79) and SD15—Assessment and Evaluation Methods (75.22) highlight the strengths in providing accessible learning materials and adopting innovative evaluation techniques. However, SD13—Student Admission, Learning Process, and Graduation (70.02) suggests areas for improvement in managing the student lifecycle and enhancing online learning platforms.

MD2—Digital Infrastructure score (71.11) indicates substantial progress in technological investments. Notably, SD10—Technological Equipment (72.90) reflects the institution's commitment to acquiring critical digital resources. However, the moderate performance in SD9—Cybersecurity (70.21) and SD6—Information Management Systems (68.86) points out the vulnerabilities in data protection and system integration that require immediate action.

MD5—Communication and Collaborations, with a score of 70.72, highlights the effective external partnerships, as shown in SD18—Collaborations with Industry, Academic, and Other Institutions (71.06) and SD20—Student Information (71.62). However, the internal communication processes (SD19—Internal Communication, 69.98) and the functionality of external-facing platforms (SD21—Website, 70.64) emerge as critical areas for development.

MD1—Management and Leadership scored 70.43, reflecting notable strategic planning capabilities. The sub-dimension SD4—Strategic Planning (78.47) demonstrated the strongest performance, showcasing the institution's ability to align resources with long-term goals. Nevertheless, SD2—Financial Management (64.13) and SD5—Process Management (64.32) revealed operational inefficiencies that may hinder these objectives.

Finally, MD6—Human Resources, with the lowest score of 67.15, underscores significant challenges in staff-related digital transformation practices. While SD22—Digital Skills of Staff (73.65) pinpoints progress in enhancing competencies, SD23—Recruitment (65.16) and SD24—Performance Development and Evaluation (62.66) indicate the need for targeted efforts to cultivate a digitally proficient workforce.

5 Conclusions and discussions

Higher education institutions serve as key drivers of social progress and change. In this evolving landscape, digital transformation has emerged as a vital step in their advancement. Assessing the degree of digitalization in universities, pinpointing opportunities for growth, and deploying targeted improvement strategies are all essential steps in shaping their future trajectory. This study develops a comprehensive framework for assessing the digital maturity level of a higher education institution. Drawing on empirical evidence from in-depth semi-structured interviews and a survey conducted with academics, administrative staff, and students at a foundation university in Eastern Europe, the research proposes a digital maturity model comprising six main dimensions and 24 sub-dimensions. The integration of Picture Fuzzy SWARA and comparisons to Fermatean and Hesitant fuzzy approaches enabled a robust weighting and evaluation of the model.

The results show that the digitalization level of the university is 71.26 and it is classified as e-Confident, indicating that it is effectively using DT and has a high level of maturity in its digital processes, though certain areas for improvement remain. Digitalization and innovation in research (74.71) emerged as the strongest area, strongly emphasizing integrating digital tools and databases into scholarly activities. Learning and teaching applications (73.04) also showed considerable progress, particularly in providing accessible resources and modern assessment methods. However, deficiencies were identified in student lifecycle management (70.02) and online education system (71.13), indicating challenges in sustaining learner-centered digital practices.

Similarly, digital infrastructure (71.11) was supported by investments in equipment but constrained by weaknesses in cybersecurity (70.21) and information management systems (68.86). Communication and collaborations (70.72) were satisfactory in external engagement but weakened by internal communication inefficiencies (69.98) and suboptimal website functionality (70.64). The lowest-performing domain was human resources (67.15), particularly in recruitment (65.16) and performance evaluation (62.66), which may jeopardize the sustainability of the institution's digital transformation. These findings underscore the necessity of adopting an integrated strategy combining technological, organizational, and human resource dimensions to achieve higher maturity levels.

The results of the study provide three important outcomes about digital maturity in HEI. First, looking at the hierarchical positioning of the dimensions (research: 74.71; teaching: 73.04; infrastructure: 71.11; communication: 70.72; management: 70.43; human resources: 67.15), the present study shows the importance of the "technology-first, people-second" paradigm in educational digitalization as claimed by Selwyn [47]. This finding indicates that HEI usually focus on the technical infrastructure that supports the core business of education, i.e. databases, equipment, software, first and then turn to the organizational dimensions. Secondary-positioning of human resources, who are the main actors of implementing institutional strategies, is a challenge in realizing digitalization goals. For a sustainable digitalization, HEI should build technical and organizational capabilities simultaneously. This is in line with the findings of prior studies [41, 59].

Second, our multi-stakeholder analysis has shown that the priorities of the different groups in the university are not the same. Students rank the most important factors as being easy-to-use learning environments and access to resources (SD12-SD14), while academics are mainly concerned with research facilities and database integration (SD16-SD17). Administrators staff rank improving the efficiency of administrative procedures (SD6-SD7) as their highest priority. The implications of these divergent views are quite important: a digital project that meets the needs of administrators may not be useful to students or may go unnoticed by academics as asserted by Henderson et al. [25]. HEI structure management frameworks that would bring all stakeholders together to bargain their competing demands to improve their collaborative capabilities.

Finally, this research explored whether the outcomes would change when employing different analysis techniques. In this study, three different fuzzy techniques—Picture, Fermatean, and Hesitant—are employed, andd the digital maturity scores varied by only a fraction of a percent (from 71.25 to 71.40, a mere 0.2% difference). This result further reinforces confidence in the validity and reliability of the proposed framework. This methodological robustness serves to enhance its practical utility, as decision-makers can utilize the framework without being concerned that minor technical variations will have a significant impact on strategic inferences.

To sum up, within a sociotechnical discourse, DM in higher education is not a destination achieved through only technical acquisition, but a continuous negotiation between infrastructure and human resources. The study shows a structural decoupling where high-performing technical domains, such as research and teaching, outpace institutional capacity to manage human capital driving them. From a technical perspective, the robustness of the fuzzy logic framework validates that the university has successfully established the hard components of transformation. However, the identified weaknesses in information management and cybersecurity suggest that digital foundation is technically functional but strategically vulnerable.

From a social point of view, the “technology-first, people-second” paradigm remains a significant barrier. The lag in recruitment and performance evaluation indicates that the workforce is not yet systematically incentivized or curated to lead the change implemented by digital tools. For the institution to transition from being digitally capable to being truly digitally mature, it must bridge the priority gap between stakeholders by aligning the administrative drive for efficiency with the needs of students and the scholarly demands of academics. One major difference between the DM assessment for HEI and other institutions is the significant role universities play in the development of DT. However, very few HEI have grasped the importance of digitalization and integrated it into their management systems and processes such as the management of education and research activities. This situation stems partly from the nature of processes like education and research, which are difficult to standardize.

5.1 Implications of the study

This study provides is a novel digital maturity model with multi-dimensional and stakeholder-driven features designed explicitly for HEI. In contrast to the previously developed models that focus on technical infrastructure [57] and pedagogical practices [18, 30, 32], our framework combines managerial, academic, and human resource dimensions, providing a holistic view of digital maturity in HEI. In this sense, this study offers practical implications for HEI and policymakers. First, the research shows that digital maturity can not be solely evaluated considering infrastructure investment. There is a need for a systemic alignment of leadership, governance, staff capacity, and communication mechanisms. Therefore, HEI executives should prioritize integrating management information systems to foster coordination and reduce fragmentation across the units. Second, the results reveal that human capital is an important matter for digital transformation. Although digital skills could be developed, recruitment and performance management deficiencies may lead to structural issues in cultivating a digitally competent workforce. Thus, staff planning, professional training and performance evaluation policies should align with digital transformation strategies. Third, the findings show that student-based digital processes, particularly admissions, online learning and graduation services are important. Accurately addressing these issues is vital to ensure student-centered digital journeys and experiences. In this frame, it is importance for HEI to design digital tools based on student opinion and feedback, fostering user-friendly and inclusive systems that enhance engagement and satisfaction. Finally, the fuzzy MCDM methods applied in this study provide a nuanced way to capture uncertainty through expert evaluation. The consistency in results across different fuzzy approaches ensures the robustness of the proposed model and its high adaptability to diverse higher education contexts. Policymakers can employ the proposed framework as a benchmarking tool for designing digital management systems at different scales.

5.2 Limitations and future research

We acknowledged that this study has certain limitations. First, it is conducted for only a single foundation university in Eastern Europe, limiting the generalizability of the findings. Therefore, the results may not fully reflect the diverse characteristics of all European HEI. Public universities may face unique challenges in their digital transformation efforts. Future research may encompass a broader range of HEI to generalize the applicability of the proposed digital maturity model. Second, the rapid pace of technological advancements poses significant challenges for static assessment frameworks. As digitalization has a dynamic nature and digital technologies continuously evolve, the needs and priorities of HEI are likely to shift in the future. Future studies should explore the integration of adaptive mechanisms within the digital maturity model to account for technological advancements and the evolving expectations of stakeholders to ensure the model's responsiveness to the changing landscape of higher education.

Abbreviations

DM	Digital maturity
DT	Digital technologies
EC	European Commission
FFNs	Fermatean Fuzzy Numbers
HEI	Higher education ınstitutions
HFNs	Hesitant fuzzy numbers
ICT	Information and communications technology
MCDM	Multi-criteria decision-making
OECD	Organisation for Economic Co-operation and Development
PF	Picture fuzzy
PFSs	Picture fuzzy sets
SWARA	Stepwise weight assessment ratio analysis

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Author contributions
MKY managed and directed the research plan, ŞŞ studied the literature and prepared the interview questions, MZ and MA Bulut conducted the interviews and survey, AOK conducted the Fuzzy SWARA analysis.

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Data availability
The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Ibn Haldun University Ethics Committee Board for Social Sciences and Humanitites Research and Publication Ethics and the reference number is 2023/0701 in compliance with Declarations of Helsinki (DoH). Informed consent was obtained from all individual participants included in the study.

Consent for publication
Not applicable. All data were anonymised, and no individual participants can be identified.

Competing interests
The authors declare no competing interests.

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